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GI SOUP IN A NETWORK CENTRIC POT: A MARITIME PERSPECTIVE ON GEOSPATIAL INFORMATION IN A NETWORK CENTRIC ENVIRONMENT
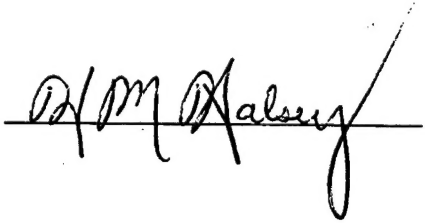
by

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As an Advanced Research Project

A paper submitted to the Director of the Advanced Research Department in the Center for Naval Warfare Studies in partial satisfaction of the requirements for the Master of Arts Degree in National Security and Strategic Studies.

The contents of this paper reflect my own personal views and are not necessarily endorsed by the Naval War College or the Department of the Navy.

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The purpose of this paper is twofold. First, it is to familiarize, review, and/or update the reader with geospatial information concepts and issues. Secondly, the purpose is to promote a shared vision of geospatial information related objectives, strategy, and policies that support a network centric environment and operational concept – a common framework for program implementation decisions.

The analysis of these concepts and issues will support the position of this paper that object-oriented databases are the database of choice for geospatial information, of various data model structures, is registered in object-oriented databases in an appropriate format, then it will support network centric concepts for situational awareness applications.

Balancing production requirements against technology and future concepts, this paper recommends that National Imagery and Mapping Agency (NIMA) continue to produce and distribute vector product format based products. At the same time NIMA should continue to transition this data to object-oriented data structures for updating existing products and eventual shift to pure object-oriented databases.

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eventual shift to pure object-oriented databases.

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CHAPTER I

INTRODUCTION

To support decision making, many users still rely on hardcopy maps and charts and employ manual overlays to integrate and analyze information.... Some users have state-of-the-art automated information tools, but lack the type of data and area coverages needed to support their missions....Within [the Department of Defense,] today's warrior...must deal with the inability to effectively integrate digital data from stove-piped information flows. [Integrated Product Team, 1997]

Users must have interoperable tools that will allow them to produce both standard and tailored views of the needed information, as well as the ability to disseminate views as operationally required (i.e., in digital or hardcopy form). They must have a consistent set of near global geospatial information.... [Integrated Product Team, 1997]

[As illustrated in figure 1,[1]] future decision aids will build upon these capabilities to present relevant information in ways that assist human thought and decision making. To do this, the information must be sufficiently complete, current, positionally correct, and accurately described....Any uncertainties in information must be communicated effectively, and information from various sources must be logically integrated. Displays must present information relevant to tasks without losing context, and users must be able to query, or "drill down" to any information that might be critical to understanding a situation.[2]

Figure 1

Command Center of the Future

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[1] David Gunning, Command Post of the Future, 20 October 1998, <http://www.darpa.mil/iso/cpof/main.html>, 14 January 1999.
[2] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 4-5.

1

"Information superiority is a precondition to Full Spectrum Dominance sought for our Armed Forces in the 21st century. The Chairman's Joint Vision 2010 (JV 2010) notes that dominant maneuver, precision engagement, full dimensional protection, and focused logistics all depend on information superiority....Information superiority depends on shared geospatial information"[3] "in which the national security decision maker and warrior can spatially relate friendly and threat situations in the context of mission space. It is now technically feasible to co-register what has been separate views of mission space, bringing everything to the common geometry established in the geospatial Framework."[4]

As the Chief of Naval Operations, Admiral Jay Johnson recently articulated:

> This is an exciting time...a time of great promise and a time to make bold plans for the future. We stand on the threshold of a new century, in an era of almost dizzying technological change. Change is our ally. It presents an unprecedented opportunity to transform the face of warfare....[5]

This paper is about geospatial information and technological change. The paper describes what geospatial information is, help users understand that it has various levels of abstraction associated with it, and conceptualize how the bigger picture of geospatial information relates to the nature of future warfare.

The purpose of this paper is twofold. First, it is to familiarize, review, and/or update the reader with geospatial information concepts and issues. Secondly, the purpose is to promote a shared vision of geospatial information related objectives, strategy, and policies that support a network centric environment and operational concept - a common framework for program implementation decisions.

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[3] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 1.
[4] Ibid., 7.
[5] Jay Johnson, "Anytime, Anywhere: A Navy for the 21st Century," U.S. Naval Institute Proceedings, November 1997, 48.

The geospatial information environment is riddled with terms, and numerous acronyms that are intimidating, if not overwhelming. To make matters worse, many of the terms have fallen by the wayside in favor of new terms; however, many of the old terms are still frequently used and found throughout literature. This paper endeavors to present these concepts and associated terminology, and help users put them in perspective.

This journey starts with what geospatial information is and why it is important. Then endeavors to develop a "big picture" depicting the approach used in this paper to examine geospatial information concepts and their relationships to one another. From there, this paper takes a top-down; bottom-up look at those geospatial information related concepts. You will find qualitative analysis throughout the paper, and it concludes by comparing solution sets within the geospatial information solution space.

The analysis of these concepts and issues will support the position of this paper that *object-oriented databases are the database of choice for geospatial information.* The paper concludes that *if geospatial information, of various data model structures, is registered in object-oriented databases in an appropriate format, then it will support network centric concepts for situational awareness applications.*

CHAPTER II

GEOSPATIAL INFORMATION

What is Geospatial Information?

Geospatial information is data that "identifies the geographic location and characteristics of natural or constructed features and boundaries on the earth."[6] It is:

> geographical (or spatial) data [that] represent phenomena from the real world in terms of (a) their position with respect to a known coordinate system, (b) their attributes that are unrelated to position…and (c) their spatial interrelations with each other which describe how they are linked together….[7]
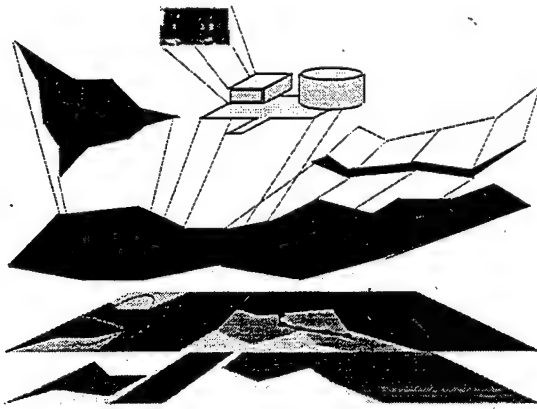
Figure 2

Geospatial Information

Hence, it is data that describes entities, or objects, and continuous fields as a function of space, time, attributes,[8] and context. It is information "produced by multiple sources to common interoperable data standards"[9] that represents the mission space and is relatively stable over time, as illustrated in figure 2.[10]

Types of data that comprise geospatial information include "geodetic, geomagnetic, imagery (both commercial and national source), gravimetric, aeronautical, topographic, hydrographic, littoral, cultural, and toponymic data."[11]

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[6] "Glossary of FGDC Metadata Standard Terminology." FGDC Glossary. <http://www.tidalzone.com/downloads/FGDCglossary.html> (15 January 1999).

[7] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 11-12.

[8] Attributes can be physical dimensions of an object, spectral signature, magnetic signature, gravimetric signature, etc., for example the physical attributes associated with an aid to navigation.

[9] Joint Chiefs of Staff, JTTP for Geospatial Information and Services Support to Joint Operations (Joint Pub 2-03) Final Coordination (Washington D.C.: February 20, 1998), GL-3.

[10] Adapted from Dynamic Situation Model figure by Tom Burns, Major, USAF, "Technical Description" Dynamic Database. <http://dtsn.darpa.mil/iso/programtemp.asp?mode=128> (27 October 1987).

Why is Geospatial Information Important?

Diverse communities share a requirement for geospatial information. Civil, academic, and commercial domestic security related applications include "urban planning, agriculture management, weather monitoring, disaster relief, and environmental cleanup." National security applications "support diplomacy, non-combatant evacuation operations, assessment of national security threats, humanitarian and disaster relief efforts, and the deterrence of war. The defense and intelligence community needs geospatial information" to realize the tenants associated with Joint Vision 2010.[12]

As illustrated in figure 3,[13] "Digital geospatial information forms the foundation for battlespace visualization. When geospatial information is coupled with threat analysis, meteorological and oceanographic environmental intelligence, the friendly situation, and the logistic situation, the commander can more quickly grasp the view of the battlespace."[14]
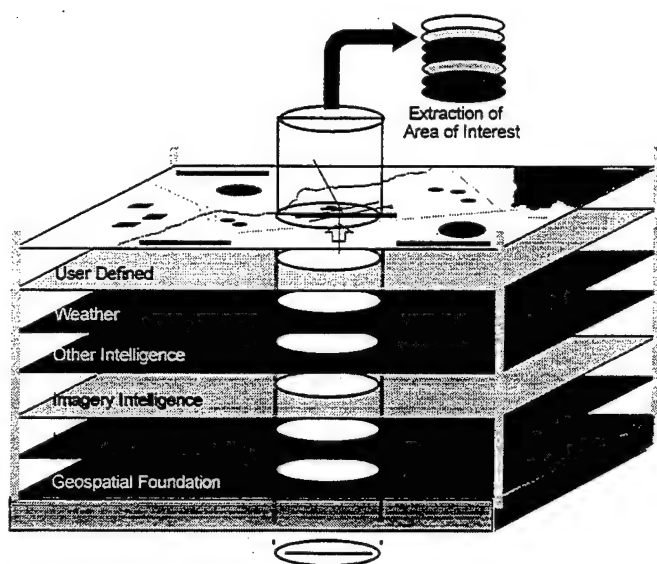
Figure 3

Integrated Picture of the Mission Space

[11] Joint Chiefs of Staff, JTTP for Geospatial Information and Services Support to Joint Operations (Joint Pub 2-03) Final Coordination, (Washington D.C.: February 20, 1998), GL-3.

[12] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 3-4.

[13] National Imagery and Mapping Agency, "Common View of the Mission Space," USIGS Architecture Overview, <http://www.nima.mil/aig/briefings/overview/sld007.htm> (15 January 1999).

[14] Joint Chiefs of Staff, JTTP for Geospatial Information and Services Support to Joint Operations (Joint Pub 2-03) Final Coordination, (Washington D.C.: February 20, 1998), I-1.

CHAPTER III

BACKGROUND

The face of military mapping has been altered profoundly over the last two decades by the proliferation and increasing power of computers in the hands of the warrior, by the power of the computer for the mapper, by the orbiting of civil remote-sensing satellites and of a constellation of navigation satellites, and by the fall of communism, the related rise in regional instability, and adjustments of military strategy, forces, and doctrine in response to these changes.[15]

Organizations

"The increasing use of electronic navigation systems has made the navigator dependent on many factors outside his control. Government organizations fund, operate, and regulate satellites, LORAN [long range navigation], and other electronic systems....In the United States, there are a number of official organizations which support the interest of navigators. Some have a policy-making role; others build and operate navigation systems. Many maritime nations have similar organizations performing similar functions. International organizations also play a significant role."[16]

This section introduces important organizations at the international and national level, which are relevant to maritime applications of geospatial information.[17] The primary organizations maritime users and decision-makers will want to be familiar with are listed in table I.

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[15] National Imagery and Mapping Agency, Anticipating the 21st Century, January 6, 1999 <http://164.214.2.54/guides/dtf/intro.html> (February 1, 1999).

[16] Defense Mapping Agency Hydrographic/Topographic Center, The American Practical Navigator, An Epitome of Navigation, Pub. No. 9 (Bethesda, Maryland, 1995), 9.

[17] Additional information on these organizations can be found in "Bowditch" The American Practical Navigator, An Epitome of Navigation, Pub. No. 9, Geospatial Information & Services Maritime Navigation Handbook, Version 2.0, and associated web pages.

Table I

Organizations Relevant to Maritime Applications of Geospatial Information

ORGANIZATION	FUNCTION
International Organizations	
International Hydrographic Organization (IHO)	Chart content and functionality, and data format(s)
International Maritime Organization (IMO)	Minimum performance standards
International Electrotechnical Committee (IEC)	Equipment test standards
Department of Defense (DoD)	
U.S. Navy (USN)	Historical/technological contributions; establishing requirements, policy
Oceanographer of the Navy (N096)	Establishing requirements and policy
National Imagery and Mapping Agency (NIMA)	Combat support agency - provides imagery; imagery intelligence, and geospatial information in support of national security objectives. Represents DoD interest nationally and internationally
Defense Logistics Agency (DLA)	Map, chart, and electronic media distribution
Department of Commerce (DoC)	
National Ocean Service (NOS)	Part of the National Oceanic and Atmospheric Administration (NOAA), the National Ocean Service (NOS) provides a wide range of products and services
Coast and Geodetic Survey (CGS)	Produce charts and related information for safe navigation of the nation's waterways and territorial seas
Department of Transportation (DoT)	
U.S. Coast Guard (USCG)	Operations of the nation's aids to navigation system

New Ways of Navigation

Typically "navigating in and out of port is performed relative to fixed

landmarks....Thus, one seldom cares where the ship is in an absolute sense - i.e. exact

numerical latitudes and longitudes in a global sense are not an issue."[18]

"Advances in digital processing technology" and precise navigation systems, such as

global positioning system (GPS),[19] are significantly impacting "how one navigates regardless

of whether it's a small recreational craft," a large commercial vessel, or a naval combatant.[20]

"By using GPS and positioning yourself continuously in terms of specific latitudes and

longitudes" on electronic navigation charts, "you have changed the way you navigate in a

subtle way."[21] The subtle change is from navigation with emphasis on relative position,

which is inherently time-late, to navigation with emphasis on actual position, which can be

both real time and predictive.

To put this in context it is useful to introduce an international standard, and the

associated functionality of systems compliant with this standard, to examine how this new

way of navigation significantly enhances the safety of navigation at sea.

Processing and navigational technological advances have led to the development of

the Electronic Chart Display and Information System (ECDIS), pronounced "eck-dis." The

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[18] Zdenka S. Willis, CDR, USN, and others, Geospatial Information & Services Maritime Navigation Handbook, Version 2.0, 20 April 1998. <http://oceanographer.navy.mil/gi&s_hbk.html> (11 January 1999).
[19] For information on GPS and Differential GPS, see NAVSTAR GPS within Digitizing the Future at http://164.214.2.54/guides/dtf/index.html, TMPO GPS tutorial at http://164.214.2.54/guides/index.html, and USCG web pages at http://www.navcen.uscg.mil/links/gpslinks.htm and specifically "GPS/DGPS" within Applying the Latest Technologies at http://www.navcen.uscg.mil.geninfo/nisbrochure/intro2.htm.
[20] Chris Andreasen, "Electronic Chart Navigation – An Evolution," Sea Technology, November 1991, 101.
[21] Zdenka S. Willis, CDR, USN, and others, Geospatial Information & Services Maritime Navigation Handbook, Version 2.0, 20 April 1998. <http://oceanographer.navy.mil/gi&s_hbk.html> (11 January 1999).

International Maritime Organization (IMO) defines ECDIS "as the integrated bridge system that complies with the up-to-date chart carrying requirements of international law."[22]

In an ECDIS compliant system "the computer system displays, manipulates, modifies and updates the charts as the user wishes. It also receives signals from a positioning device such as LORAN [long range navigation], GPS...and radio beacons, which enable it to compute longitude and latitude....By using this single system, the mariner knows exactly where the ship is at any given moment."[23] ECDIS combined with expert systems technology will forewarn the mariner of impending hazards.[24]

ECDIS, similar to a flight management system, has two basic purposes: route planning and route monitoring. In the route monitoring phase the electronic navigation chart (ENC) displays the ships instantaneous position, where it has been, and where it is headed, allowing the navigator to maintain a continuous awareness of proximity to hazards. Similar to an aircraft heads-up display, that displays both platform heading and a velocity vector representing actual track, the ability of ECDIS to display both heading and ships track is advantageous in developing and maintaining situational awareness. "ECDIS simplifies turning maneuvers by allowing the navigator to effect course corrections as a turn is made."[25]

"In addition to the display benefits, the digital chart will have an automatic 'Notice to Mariners' update capability providing mariners with continuously up-to-date charts."[26]

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[22] Defense Mapping Agency Hydrographic/Topographic Center. The American Practical Navigator, An Epitome of Navigation, Pub. No. 9. Bethesda, Maryland, 1995, 220.

[23] Joe Evangelista, "Doing Away With Paper: The Electronic Nautical Chart," Surveyor, September 1992, 7.

[24] Chris Andreasen, "Electronic Chart Navigation – An Evolution," Sea Technology, November 1991, 101.

[25] Chris Andreasen, "Electronic Chart Navigation – An Evolution," Sea Technology, November 1991, 101.

[26] There are a number of ECDIS-like systems currently available in the marine market. They cover a wide range of capabilities – some have charts that cannot be updated, while others are ECDIS compliant.

Captain Peter Collom, U.S. Coast Guard, Retired, said of ECDIS:

> Never before in navigation have we been able to see where we are right now
> except to look out the wing of the bridge. You can see where you are with
> relation to a very broad area....You can get your charts, look at your courses,
> change your course, check your set and drift and look at your radar targets.
> You can call up textual information, look at notes made the last time the ship
> passed this way...all this can be displayed before you in one place. A man
> can look out from the bridge and look down at his chart and get virtually any
> information he wants.[27]

Taking this concept of operation further, "when digital radar data – which depicts the position of objects related to the ship independent of ECDIS – is combined with ECDIS, it will now be possible for a navigator to easily know if an aid to navigation is out of position. That is, the radar depiction will show the buoy offset from the chart display position and indicate how far the buoy is out of position. When these two displays have a general shift from one another, it is an indication of poor navigation input and will serve to warn the navigator of bad navigational data."[28]

Arthur Gaines of the Woods Hole Institute articulated that "the electronic chart is the principle tool in ECDIS, but it is the chart's integration with other instruments (such as radar and GPS) that really make ECDIS valuable...."[29]

Mortimer Rogoff, a pioneer in electronic charts and of the ECDIS system, said:

When you mix radar and the electronic chart display on the same screen...you can see
what is around you, water depths, obstacles and the distances between your waypoints
and your destination. You feel an instant grasp of the whole tactical situation. In low
visibility conditions, this is ideal.[30]

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[27] Joe Evangelista, "Doing Away With Paper: The Electronic Nautical Chart," Surveyor, September 1992, 7.

[28] Chris Andreasen, "Electronic Chart Navigation – An Evolution," Sea Technology, November 1991, 101.

[29] Joe Evangelista, "Doing Away With Paper: The Electronic Nautical Chart," Surveyor, September 1992, 7.

[30] Ibid.

CHAPTER IV

GEOSPATIAL INFORMATION - A PERSPECTIVE

Geospatial Information (GI)...Geospatial Information Infrastructure (GII)...

Geographic Information Systems (GIS)...Geospatial Information and Services (GI&S)...

What do they all mean and how are they related?

As illustrated in figure 4, there are a number of important concepts of varying degrees

or levels of abstraction associated with geospatial information (GI), that this paper arbitrarily

breaks down into three different "levels." While this illustration may not be complete, or

even technically correct, this paper purposes this approach as a useful tool for decision-

makers to develop perspective with respect to geospatial information (GI).

Top-down perspective
Infrastructures
  - Geospatial Information Infrastructure (GII)

Framework

Architectures

Geographic Information Systems (GIS)
Geospatial Information and Services (GI&S)
Geospatial/Framework Information
- Foundation Data
- MSDS
- Qualified Data
- Metadata

NIMA Products
Applications/Tools
Systems

Data Format Standards
Database Management Systems
Database Structures
Data Structures
Geographic Data Models
Conceptual Models

Bottom-up perspective

Figure 4

Geospatial Information – A Perspective

11

The greatest level of abstraction is associated with the Geospatial Information Infrastructure (GII), GII Framework, and the associated GII Operational, Technical, and System Architectures. This level sets the framework, or context, in which to view the other geospatial information (GI) components and is presented as a top-down perspective in chapter V. The next level of abstraction is associated with a universal concept termed Geographic Information Systems (GIS) and a federal concept that bridges GIS with the GII. This NIMA sponsored concept is termed Geospatial Information and Services (GI&S). This level is perhaps the most important because the concepts bridge the abstract with substance, from the organization of data that populate the databases to the geospatial services available to the operator. These concepts are presented in chapter VII. Grounded in substance are concepts and issues associated with data models, data structures, database structures, database management systems, and data exchange format standards. This level is presented in chapter VI as a bottom-up perspective. Additionally, chapter VIII provides a brief look at NIMA maritime products that are relevant to the operator. Chapter IX looks at several geospatial tools or processing services, and chapter X will further discuss standards within the context of the international and national arena.

CHAPTER V

BUILDING THE PICTURE – A TOP-DOWN PERSPECTIVE

Geospatial Information Infrastructure

The Geospatial Information Infrastructure (GII), as illustrated in figure 5, "is the collection of people, doctrines, policies, architectures, standards, and technologies necessary to create, maintain, and utilize a shared geospatial Framework."[31]
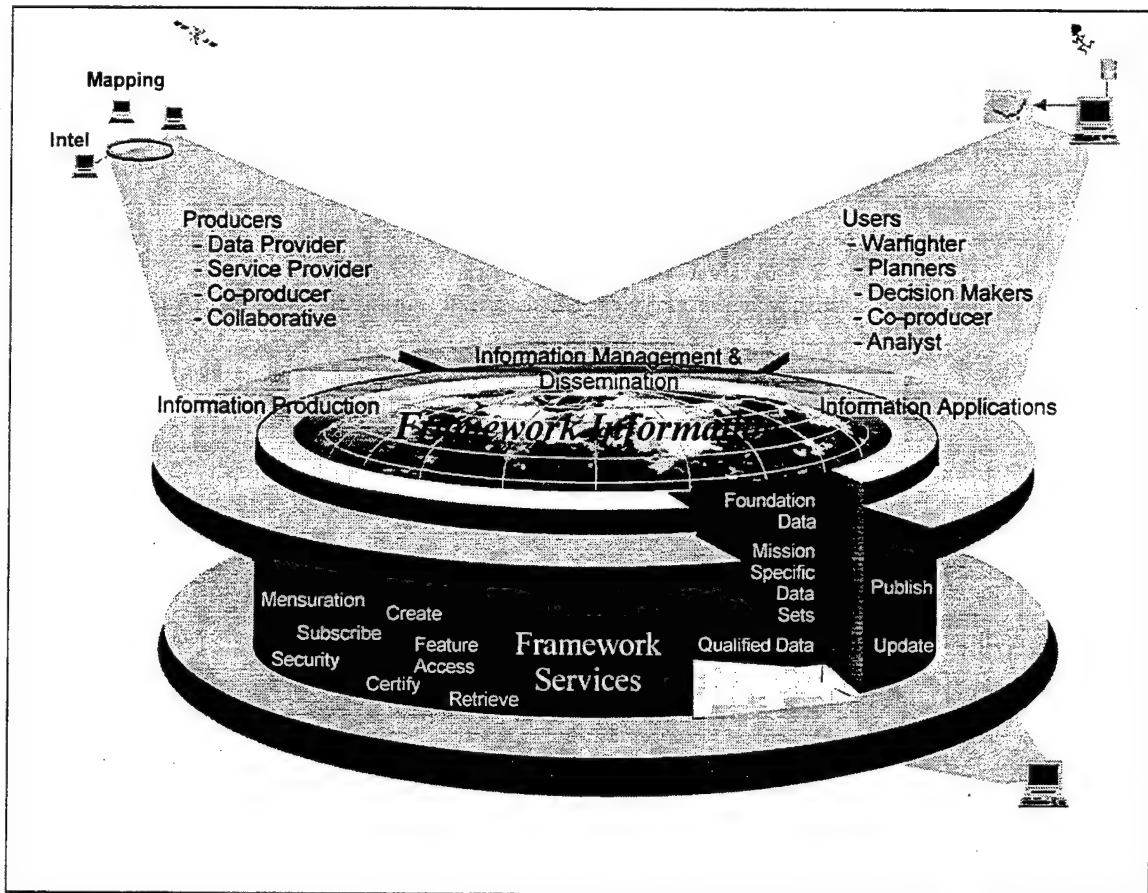
Figure 5[32]

Conceptualization of the Geospatial Information Infrastructure

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[31] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 23-24.
[32] Ibid., 23.

The GII [Geospatial Information Infrastructure] is based on the development of a shared Framework of geospatial information capable of supporting standard and tailored views of the mission space in both hardcopy and softcopy form....It provides capabilities such as requirements analysis, source acquisition, data modeling, information production, information management, and communications for dissemination....The result is geospatial information that is current, sharable and usable on a variety of systems.[33]

The National Imagery and Mapping Agency's (NIMA's) goal is to provide on-line integrated access to and delivery of information. To realize this goal the Geospatial Information Infrastructure (GII) "establishes the rules and provides the mechanisms for cooperation so that diverse communities can work together to support the population and application of a common set of geospatial information....The Framework provides a blueprint to achieve geospatial interoperability through collaborative development, production and exploitation activities....This Framework will provide the common base for the fusion of information needed to support tailored views of the mission space." The Geospatial Information Infrastructure (GII) provides assured access to "a consistent set of geospatial information [of] known accuracy, quality, and lineage keyed to a shared Framework."[34]

How does the Geospatial Information Infrastructure (GII) relate to other infrastructures? The Geospatial Information Infrastructure (GII) represents the "geospatial domain within the broader evolving information technology (IT) infrastructures."[35] The Geospatial Information Infrastructure (GII), through the United States Imagery and Geospatial Information Services (USIGS), interacts with numerous information technology infrastructures and associated architectures. The intersections of these infrastructures, as

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[33] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 9.
[34] Ibid., v, vi.
[35] Ibid., 17-18.

illustrated in figure 6, mark the critical interface across which information and services must

be exchanged to assure interoperability.[36]
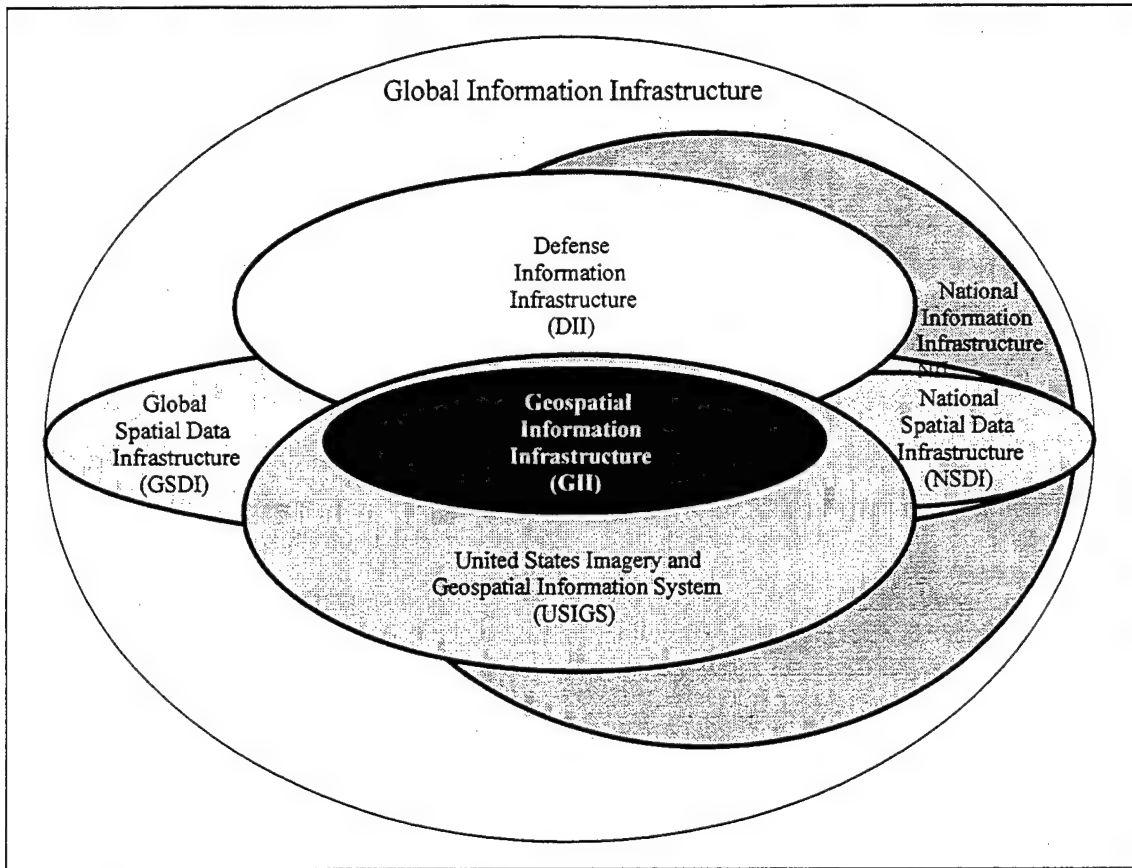
Figure 6[37]

Infrastructure Relationships

       There is a Global Information Infrastructure and a National Information Infrastructure

(NII). Spatial data is register within an international and national sub-infrastructure.

Specifically, a Global Spatial Data Infrastructure (GSDI) exists within the Global

Information Infrastructure. Likewise, a National Spatial Data Infrastructure (NSDI) exists

within National Information Infrastructure (NII). The Department of Defense (DoD) has it's

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[36] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 11-12.
[37] Ibid., 12.

own infrastructure, the Defense Information Infrastructure (DII). Besides DoD there are many other national agencies that have a requirement for imagery, imagery intelligence, and geospatial information (but not necessarily the entire DII); hence, the existence of the United States Imagery and Geospatial System (USIGS).[38] The Geospatial Information Infrastructure (GII) is a totally included component of the United States Imagery and Geospatial System (USIGS). Both the Geospatial Information Infrastructure (GII) and United States Imagery and Geospatial System (USIGS) intersect the Defense Information Infrastructure (DII) and the National Spatial Data Infrastructure (NSDI), and are components of the more loosely defined National Information Infrastructure (NII); and by extension, the Global Information Infrastructure. The Defense Information Infrastructure (DII), Geospatial Information Infrastructure (GII), and United States Imagery and Geospatial System (USIGS), "through relationships with allies and other cooperating nations, reach beyond the" National Information Infrastructure (NII) "to also be components of the information infrastructures of those other nations."[39,40]

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[38] United States Imagery and Geospatial System (USIGS) is the federation of organizations, networks, and relationships of the US Government that collectively or individually acquires, produces, and delivers imagery, imagery intelligence, and geospatial information and services to users. (NIMA Functional Manager's Guidance for the USIGS Community FY 1999-2003)

[39] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 12.

[40] The Geospatial Information Infrastructure (GII) must support the development of the architecture and standards within the United States Imagery and Geospatial System (USIGS) to ensure geospatial interoperability for the Defense Information Infrastructure (DII). It must also support the coordination of architecture and standards with the National Spatial Data Infrastructure (NSDI) to ensure geospatial interoperability for the National Information Infrastructure (NII).

Geospatial Information Infrastructure Framework

The Geospatial Information Infrastructure (GII) Framework, as illustrated in figure 7, "is composed of user services and a consistent set of geospatial information," which "provide a coherent frame of reference to support the formation of an integrated view of the mission space."[41,42]
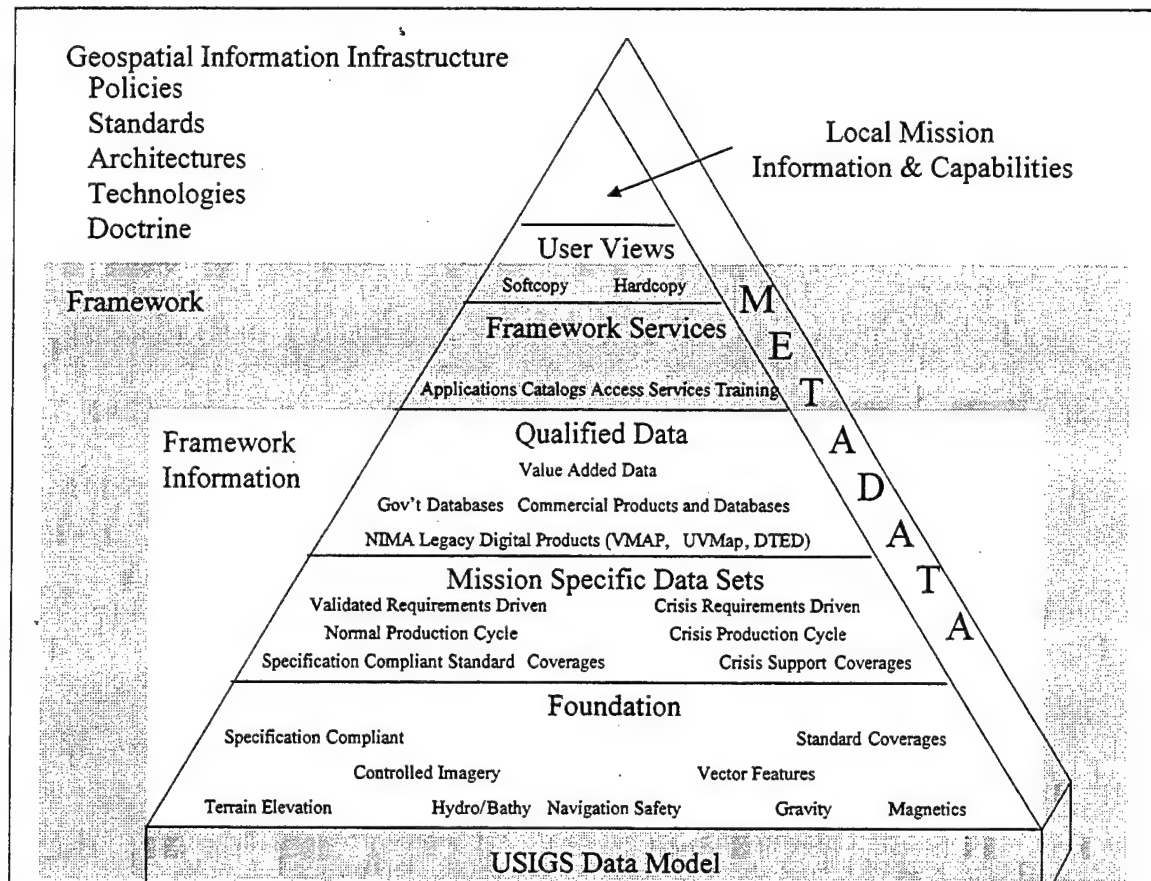
Figure 7[43]

Geospatial Information Infrastructure Framework

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[41] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 24.

[42] Framework Information will conform to a coordinated data model (the United States Imagery and Geospatial System (USIGS) Data Model) which captures the logical data structures, definitions, and relationships of all required imagery, imagery intelligence, and geospatial information. The intent is to align the United States Imagery and Geospatial System (USIGS) efforts with other international, civil and commercial modeling activities, which will contribute towards interoperability.

Framework Information, including Metadata, and Framework Services are discussed

in chapter VII under the context of Geospatial Information and Services (GI&S). The

remainder of this chapter discusses Geospatial Information Infrastructure (GII) Architectures.

Architectures to Support the Geospatial Information Infrastructure

The Geospatial Information Infrastructure (GII) is implemented within the United

States Imagery and Geospatial Information System (USIGS) architecture.[44,45] As illustrated

in figure 8,[46] the four core components of the Geospatial Information Infrastructure (GII)

Architecture, are the Data Architecture, Operational Architecture, System Architecture, and Technical Architecture.

Figure 8

Conceptualization of the
Geospatial Information Infrastructure Architecture

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[43] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 24.

[44] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 33.

[45] Architecture is the structure of components, their interrelationships, and the principles and guidelines governing their design and evolution over time.

[46] Modified from NIMA's "C4ISR Architecture Views" USIGS Architecture Overview. <http://www.nima.mil/aig/briefings/overview/sld009.htm > (15 January 1999).

Data Architecture. "Data architecture provides the common data modeling and terminology need to integrate each of the user component architecture views." Common data and modeling are necessary to support seamless information access and interoperability.[47] Chapter VI, discusses data structures, databases associated with the data architecture, and data product format exchange standards.

Operational Architecture. "The operational architecture describes the operational elements, assigned tasks and information flows required to accomplish mission functions. It is driven by the mission needs and operational requirements of the users and describes the types of information, the frequency of exchange, and what tasks are supported by these exchanges." The five main components of the Geospatial Information Infrastructure (GII) operational architecture are requirements management, data acquisition, information production, information management and dissemination, and information applications.[48]

Technical Architecture. The technical architecture supporting the geospatial domain stems from the United States Imagery and Geospatial Information System (USIGS) technical architecture. "The technical architecture documents the standards, standard profiles, and reference models...."[49] Currently, United States Imagery and Geospatial Information System (USIGS) Technical Architecture standards include, among others: Vector Product Format (VPF), Raster Product Format (RPF), World Geodetic System 1984 (WGS 84), and the United States Imagery and Geospatial Information System (USIGS) Data Model.[50]

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[47] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 33-34.
[48] Ibid., 34.
[49] Ibid.
[50] National Imagery and Mapping Agency, "USIGS Technical Architecture Current Standards, Conventions, Guidelines." USIGS Architecture Overview. <http://www.nima.mil/aig/briefings/ovrview> (15 January 1999).

<u>System Architecture</u>. "The system architecture describes the component hardware, communications, and software systems that support accomplishing the mission."[51] Communications and Automated Data Processing (ADP) systems and networks[52] provide "the basic framework for the timely dissemination of current digital geospatial information."[53,54] The National Imagery and Mapping Agency (NIMA) coordinates national communications and computer structure for Framework support to combatant commands and intelligence agencies. Combatant commands and intelligence agencies use these same standards and data formats for transmitting geospatial data to subordinate commands and joint forces.[55]

To fully exploit the Geospatial Information Infrastructure (GII) users will access the National Imagery and Mapping Agency's (NIMA's) central library, a regional library, or a local data store.[56] Network connections may be via the Internet, Global Broadcast System (GBS), Joint Worldwide Intelligence Communications System (JWICS), or SECRET Internet Protocol Router Network (SIPRNET) as illustrated in appendix A, figure 1.[57]
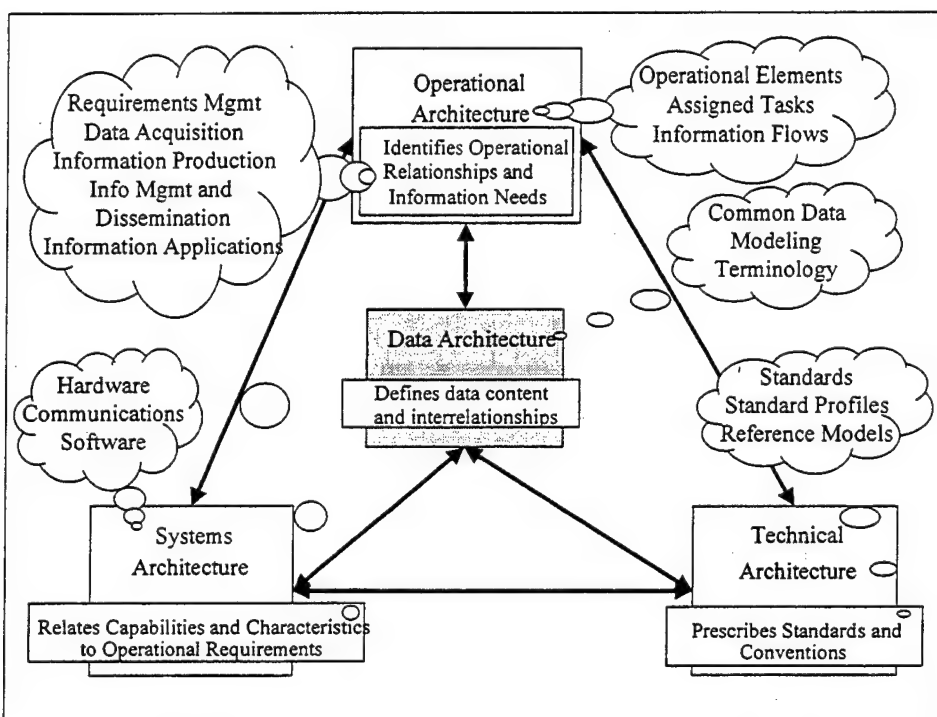
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[51] Integrated Product Team, <u>Geospatial Information Infrastructure Master Plan: Vol. I, Overview</u>, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 34.

[52] <u>JTTP for Geospatial Information and Services Support to Joint Operations</u> Joint Pub 2-03 provides a good overview of communications systems as well as communication and ADP systems and networks.

[53] Joint Chiefs of Staff, <u>JTTP for Geospatial Information and Services Support to Joint Operations</u> (Joint Pub 2-03) <u>Final Coordination</u> (Washington D.C.: February 20, 1998), IV-1.

[54] Digital geospatial data will be available on global or regional servers that are accessible by users through several methods. Geospatial data may also be distributed on electronic media and shipped to users worldwide. Every effort should be made for units to deploy with the most current geospatial data on electronic media. Pre-positioned geospatial data will limit the load on communications bandwidths.

[55] The Combatant Command Joint Intelligence Officer (J-2), the Geospatial Information and Services (GI&S) Officer, and the Joint Command, Control, Communications, and Computer Officer (J-6) collaboratively are responsible for a tailored, integrated communications architecture which links the Joint Force Commander (JFC) and subordinate forces with National Imagery and Mapping Agency (NIMA) and other national, Service, and theater-level databases and production capabilities.

[56] The data warehouse is supported by a communications architecture that allows the user to browse and download relevant data, and allows designated users to provide more current information to update the data set. Software tools provide the means to exploit the data for specific uses.

[57] The Defense Information Systems Network (DISN) provides large capacity lines and access to the Joint Worldwide Intelligence Communications System (JWICS) and the Secret Internet Protocol Router Network (SIPRNET)

CHAPTER VI

BUILDING THE PICTURE – A BOTTOM-UP PERSPECTIVE
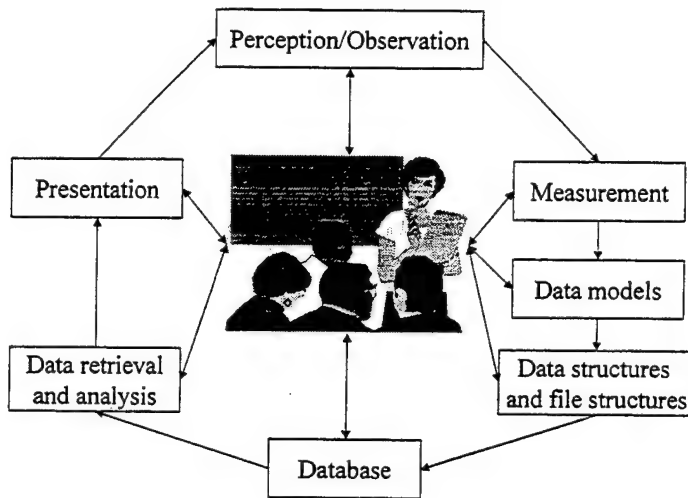
Figure 9

Digital Spatial Data Sets
Model Development and Abstraction

Data and databases are often described in terms of their format,[58] structure,[59] and content.[60] An approach to understanding geographical data and databases is through model development and abstraction. As illustrated in figure 9,[61] digital spatial data sets involve seven levels of model development and abstraction.

We begin with the geospatial information conceptual model,[62] our view or perception of reality. The conceptual models presented are entities and continuous fields. Following the levels of model development and abstraction listed in appendix B, table I, the conceptual

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[58] Format is the way in which data are systematically arranged for transmission between computers, or between a computer and a device. (Burrough and McDonnell, 1998) Often referred to as format exchange standard, such as Vector Product Format (VPF), format supports interoperability.

[59] Structure, in the context of data structure, is the organization of data in ways suitable for computer storage and manipulation. (Burrough and McDonnell, 1998) The three data structures this paper will focus on are raster, vector, and objects.

[60] Content, in the context of geospatial data, is a function of the structure, but normally is spatial, temporal, contextual, and attribute data. In can also be metadata. All these are discussed in further detail in chapter VII.

[61] Adapted from Figure 2-1, Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 18.

[62] Conceptual model is the abstraction, representation, and ordering of phenomena using the mind. (Burrough and McDonnell, 1998)

model is formalized into spatial data models.[63] Physical computational models represent data

structures (e.g., raster, vector, and objects) and file structures within database models[64] in the

computer memory. The data manipulation model is the accepted axioms and rules for

handling the data. Fundamental geospatial data axioms are listed in appendix B, table II.

The graphical data model is the accepted rules and procedures for displaying and presenting

spatial data to people.[65]

As illustrated in figure 10, we begin with conceptual models. While we are talking
about spatial data, it is easier to discuss graphical data models, as compared to spatial data models, because of our ability to relate to the context of displaying and presenting data. Then, moving away from the abstract, this chapter addresses data structures, database structures, database management systems,[66] and data format standards.

Conceptual Models ➡	Graphical Data Models
- Entity ➡	Vector Data Model Object-oriented Data Model
- Continuous Field ➡	Tesselations (triangular, square, hexagon) - Raster Data Model

Figure 10

Conceptual Models to Graphical Data Models

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[63] Spatial data model (or geographic data model) refers to the schema used for representing data that has both location and characteristic. (Burrough and McDonnell, 1998) Spatial data models raise issues such as datums.
[64] Database models include hierarchical, network, relational, object-oriented, deductive, and hybrid-relational database. (Burrough and McDonnell, 1998) This paper will focus on relational, object-oriented, and a hybrid-relational database called object-relational.
[65] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 18.
[66] Database management system is a set of computer programs for organizing the information in a database (Burrough and McDonnell, 1998).

Conceptual Models

Conceptual models perceive space either as being occupied by a series of *entities*[67] or as a *continuous field* of variation with no distinct boundaries (i.e., mathematical function). "Both the entity and continuous field models assume that phenomena can be specified exactly in terms of both their attributes and spatial position."[68]

```
┌─ Entities
├── Geographic Location
├── Attributes (properties)
└─ Relationships
   ├── Geometrical (topology)
   ├── Hierarchical
   └── Geometrical and Hierarchical
```
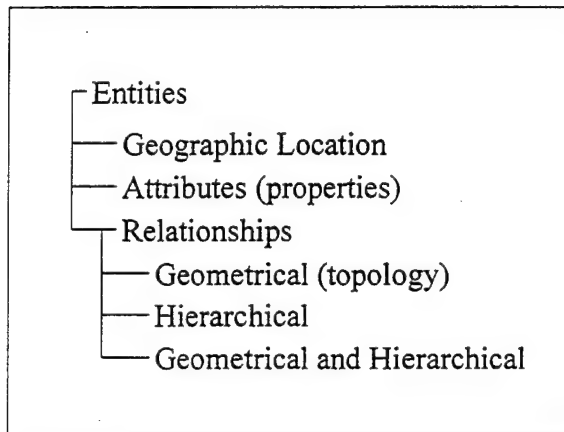
Figure 11

Entity Conceptual Model

As illustrated in figure 11, entities "are defined in terms of their geographical location (spatial coordinates or geometry), their attributes (properties) and relationships (topology). These relationships may be purely geometrical (with respect to spatial relations or neighbors), or hierarchical (with respect to attributes) or both."[69] Entities obey basic axioms of information systems, including that which says it is possible to create a wide variety of objects by combining various blocks in different ways.

The continuous field approach "represents geographical space in terms of continuous Cartesian coordinates in two or three dimensions (or four if time is included). The attribute is usually assumed to vary smoothly and continuously over that space."[70] Examples include "air pressure, temperature, elevation above sea level, [and] clay content of the soil." Clusters of like attribute values in geographic space or time may be recognized as "things."[71]

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[67] Entities are sometimes called objects, but not to be confused with objects in the object-oriented approach.
[68] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 22.
[69] Ibid., 28.
[70] Ibid., 20.
[71] Ibid.

Geographical Data Models

As illustrated in appendix A, figure 3, geographical data models are

comprised of geospatial primitives and complex discrete data models.

> Geographical data models are the formalized equivalents of the conceptual
> models used by people to perceive geographical phenomena...they formalize
> how space is discretized into parts for analysis and communication and
> assume that phenomena can be registered. As data may be collected in a
> variety of ways, information on the method or the level of resolution of
> observation or measurement may also be an important part of the data
> model....The simplest and most frequently used data model of reality is a
> basic spatial entity which is further specified by attributes and geographic
> location. This can be further subdivided according to one of three basic
> geographical data primitives, namely a 'point', a 'line', or an 'area' (which is
> most usually known as a 'polygon' in GIS [Geographical Information
> System])....These are the fundamental units of the vector data
> model....Alternative means of representing entities using tessellations of
> regular-shaped polygons are to use sets of pixels.[72,73]

"Continuous surfaces can be discretized into sets of single basic units, such as square,

triangular, or hexagonal cells, or into irregular triangles or polygons...which are tessellated

to form geographical representations."[74] In the "regular tessellation or regular grid"

approach the two-dimensional "geometric surface is divided into square cells (known as

pixels) whose size is determined by the resolution that is required to represent the variation

of an attribute for a given purpose. The grid cell representation of space is known as the

Raster data model....When the grid cells are used to represent the variation of a continuously

varying attribute each cell will be assumed to be mathematically continuous...."[75]

Considerations for picking the right geographic data model are listed in appendix B,

table III.

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[72] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 21-22.
[73] Tessellation is the process of dividing an area into smaller, contiguous tiles with no gaps in between them.
[74] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 24.

Data Structures

Two common types of digital data structures are raster and vector. They are "methods of representation, just like colored-ink-on-paper and printed-words-and-numbers-on-a-page are methods of representation."[76] Object-oriented data structures are also discussed.

Raster Data Structure. A matrix of evenly spaced rows and columns of pixels characterize the raster data structure. The pixel (short for "picture element") is the smallest non-divisible part of a digital image. A pixel typically represents a value at a point and is characterized completely by gray-scale brightness and/or color. The row and column of each pixel location determines the geospatial position.

Raster data typically represents image data. Sources include remote sensing and scanned objects, for example, imagery and raster scanned maps and charts. General characteristics associated with the raster data structure is that it is space efficient (trade pixel size for storage needs), fast, and simplifies calculations. However, excessive magnification of a raster image degrades the visual fidelity and does not improve the content accuracy. "Raster is like a facsimile what you see is what you get!"[77]

Vector Data Structure. A data structure that uses points, lines, or areas (sometimes called polygons) to describe geographical phenomena is known as a vector data structure.[78] Vector data describes natural and cultural features and objects in a given area "by their entity descriptions (feature and attribution code) and their spatial extent (geographic position)."[79]

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[75] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 24-25.

[76] Zdenka S. Willis, CDR, USN, and others, Geospatial Information & Services Maritime Navigation Handbook, Version 2.0, 20 April 1998. <http://oceanographer.navy.mil/gi&s_hbk.html> (11 January 1999).

[77] Ibid.

[78] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 40.

As illustrated in appendix A, figure 4, vector data is physically organized into five

hierarchical levels: Database Level, Library Level, Coverage Level, Feature Class Level, and

Primitive or Theme Level.[80] "VPF databases consist of one or more libraries. Libraries

contain data over a specific geographic area at a specific map scale. A library is composed of

one or more coverages which are thematic groups such as population, transportation, aids to

navigation, etc. Coverages contain one or more feature classes, each of which usually

represents a particular feature code in a feature coding scheme."[81]

Since vector data is organized in layers, the visual display of vector data is entirely up

to the user. You make the decision on what features to display, their color, line weight, and

annotations. When portrayed on a computer screen, all of the features and objects appear in

the proper physical relationship to each other, but the actual appearance scheme can be

altered or changed at any time. Vector data can also be organized to attach descriptive data

(attributes) to a vector feature (like road width and surface material).[82]

Raster and Vector Data Structures – A Qualitative Comparison. Appendix B, table

IV is an analysis through qualitative comparison of raster and vector data structures. A raster

product is a single image with no associated database - what you see is what you get.

Whereas the vector representation is a relational database, from which you can interrogate

the data. "Since the symbols in raster displays are inseparably bound to the entire image,

they cannot easily be manipulated separately; rotating raster charts yields inverted symbols

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[79] "Data Structures," Mapping, Charting and Geodetic Data, 6 March 1995,
<http://164.214.2.54/guides/dtf/struct.html> (1 December 1998).
[80] Ibid.
[81] Jerry, L. Landrum and Brian T. Wilson, Technical Review of Full Utility Navigation Demonstration (FUND)
Phase 4, Naval Research Laboratory. NRL/MR/7441—97-8049. (Stennis Space Center, Mississippi: 21
November 1997).
[82] National Imagery and Mapping Agency, "Data Structures," Mapping Charting and Geodetic Data, March 6,
1995, <http://164.214.2.54/guides/dtf/struct.html> (February 2, 1999).

and text. This does not occur with vector data, because the symbols and text are stored independently without respect to orientation. Thus, these features can be changed and displayed in any number of orientations. As you zoom raster displays, the data pixels only become bigger or smaller to the point of being unreadable. Vector data remains readable while moving through successive scales. The ability to declutter becomes increasingly important with the overlay of other layers such as radar and sonar contacts on the chart data. Raster data includes all pixels of the image including the background color. Vector data just includes the lines, points, and area boundaries, thus taking up a lot less data storage space. This means faster screen refresh, and quicker electronic transmission."[83]

Object Data Structures. Object data structures are an object-oriented approach to modeling entities. "Object-oriented (OO) refers to many technical areas, including analysis and design methodologies, languages, database construction, and database management systems."[84] Object-oriented concepts were "stimulated by the problems of redundancy and sequential search in relational structures" as well as "the need to handle complex spatial entities."[85]

Object technology is well suited for complex data modeling and localizing change effects. Objects changed the relation between data and programming code, or structures and functions. "Instead of trying to keep them apart, OOPS [object-oriented programming] deliberately merges the data and code into single entities" termed objects.[86] "The attribute and behavior variables are themselves object classes for which their properties and the

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[83] National Imagery and Mapping Agency, "Data Structures," Mapping Charting and Geodetic Data, March 6, 1995, <http://164.214.2.54/guides/dtf/struct.html> (February 2, 1999).
[84] Kevin Shaw and others, "Managing the US Navy's First OO Digital Mapping Project", IEEE Computer, September 1996, 73.
[85] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 48.
[86] "Oops!" The Economist, 28 February 1998, 82.

methods used on them are defined."[87] Advocates claim that object-oriented characteristics

"offer programmers a flexible and naturalistic means of tackling complex software design

problems."[88]

"Everything you need to know about an object is determined by its 'class'. Objects

are merely individual instances of a particular class."[89] "The thing that makes the class

system so useful is a feature called 'inheritance.' If a class of objects that responds to a

whole range of messages is suddenly required to respond to additional ones, OOPS [object-

oriented programming] allows a daughter class to be created. The daughter class inherits all

of its parent's messages but with the new ones added....Inheritance saves a programmer from

having to rewrite whole chunks of code from scratch."[90,91]

Database Structures

Four fundamental ways of organizing information, which also reflect the data models

used to model real world structures, are the hierarchical, network, relational, and object-

oriented approaches. This paper will only address relational, object-oriented, and a hybrid

approach termed object-relational.

Relational Database Structure. Relational databases work by organizing information

as a stack of tables, consisting of rows and columns, which are related to one another by

mathematical formula. Until recently massive relational databases produced by the likes of

Oracle, Sybase, and IBM have been the workhorse of corporate computing.

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[87] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 72.
[88] Maria Cobb and others, "An OO Database Migrates to the Web," IEEE Software, May/June 1998, 22.
[89] "Oops!" The Economist, 28 February 1998, 82.
[90] Ibid.
[91] The other development that has allowed the emergence of object-orientation is the creation of suitable programming languages-particularly Java, whose most famous objects, known as applets (small applications), can be fetched through the Net and put together to form full applications. Java's advent enhanced object-

"Data are extracted from a relational database through the user defining the relationship that is appropriate for the query. This relationship is not necessarily already present in the existing files....They allow different kinds of data to be searched, combined, and compared. Addition or removal of data is easy too, because this just involves adding or removing a tuple, or even a whole table....Querying across different relational tables is made by joining them through common fields. This is good for situations where all records have the same number attributes and there is no natural hierarchy. However, where the relationships between tables are complex and a number of joins are needed search capabilities suffer."[92,93]

"Relational databases are fine when it comes to dealing with words and numbers, but they tend to throw catastrophic fits if faced with the streams of video data, flashy graphics and animation...."[94] The relational model is too restrictive for spatial data applications. It lacks techniques for forming complex objects and representing spatial objects at different abstraction levels.[95]

Object-oriented Database Structure.

"Object-oriented database structures, developed using object orientation programming languages, combine the speed of hierarchical and network approaches with the flexibility of relational ones by organizing the data around the actual entities as opposed to the functions being processed....In object-oriented databases, data are defined in terms of a

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oriented benefits by providing a vehicle for running such applications across several platforms without the need for extensive cross-platform coding. Java has emerged as the OO programming language of choice.
[92] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 47-48.
[93] A tuple is a simple record, or sets of fields, each containing an attribute.
[94] "Oops!" The Economist, 28 February 1998, 82.
[95] Kevin Shaw and others, "Managing the US Navy's First OO Digital Mapping Project", IEEE Computer, September 1996, 70.

series of unique objects which are organized into groups of similar phenomena (known as object classes) according to natural structuring. Relationships between different objects and different classes are established through explicit links. The characteristics of an object may be described in the database in terms of its attributes (called its state) as well as a set of procedures which describe its behavior (called operations or methods). These data are encapsulated within an object which is defined by a unique identifier within the database."[96],[97]

"Spatial data organization in object-oriented databases has proved attractive to certain GIS [Geographical Information System] users as it offers a way of modeling the semantics and processes of the real world in a more integrated, intuitive manner than possible in relational systems....Hierarchical structuring and the representation of relatively complex relationships between object classes may be controlled directly so giving flexibility in database updating and changing."[98] An object-oriented database can handle it all; everything from text to graphics and animation to streams of video.

<u>Database Management System</u>

Computer programs used to organize and manage data in a database are known as Database Management Systems (DBMS). "Typically, a DBMS contains routines for data input, verification, storage, retrieval, and combination."[99] Database Management System

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[96] Peter A. Burrough and Rachael A. McDonnell, <u>Principles of Geographical Information Systems</u> (Oxford: Oxford University Press, 1998) 48.

[97] The structuring of objects within the database is established using pointers that refer directly to the unique identifiers. The classes and instances within them are linked by the pointers to show various relationships and hierarchies. Where hierarchies are established, forming general, sub, and super classes, various defined states or methods are passed down through the system of inheritance. This means that efficiencies may be made both in characterizing the attributes of objects and in retrieving them from the database.

[98] Peter A. Burrough and Rachael A. McDonnell, <u>Principles of Geographical Information Systems</u> (Oxford: Oxford University Press, 1998) 73.

[99] Ibid., 300.

applications "may be constructed using any of, or a combination of, the hierarchical, network, relational, and object-oriented structures….The aim of the database management system is to make data quickly available to a multitude of users whilst still maintaining its integrity, to protect the data against deletion and corruption, and to facilitate the addition, removal, and updating of data as necessary." Database management system functionality is listed in appendix B, table V.

Hybrid Relational Databases. Commercial relational databases (RDBMS), such as ARCInfo and ORACLE, "allowed designers to divide the problems of spatial data management into two parts….How to represent the geometry and topology of the spatial objects," (e.g. vector or raster data structures); and "how to handle the attributes of the spatial objects, which may be done using the commercial RDBMS. The resulting hybrid [approach, or] structures (sometimes referred to as georelational models) have a number of advantages, as listed in appendix B, table VI:

Object – Relational Database Management System. Recently, "an object-oriented approach…has been adopted in organizing both raster and vector data structures in the same GIS [Geographical Information System]. In these systems the various geometric and attribute data are stored in relational tables…and object-oriented programming languages provide analytical functionality as well as a graphical object-based interface to the data. The system allows the benefits of object-oriented organization of geographical data to be exploited within the well-known relational database environment."[100]

All the leading manufacturers of relational databases have been trying to add object-orientation to their relational products. "So far, however, developers have found that

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[100] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 72.

extracting information from a relational database becomes extremely complicated when it includes objects.[101]

Relational-hybrid versus Object-orientation. "Object-orientation is useful when entities share attributes or interact in special ways." Object-oriented systems permit relations, functionality, persistence, and interdependence to be built into one system at the expense of the programming tools being more complex and heavier demands on the computing power. "The relational approach is good for retrieving objects on the basis of their attributes, or for creating new attributes and attribute values from existing data." Relational systems are open, flexible, and adaptable, but may suffer from large data volume, redundancy, and long search times. These techniques are often used together in spatial information systems.[102]

Appendix B, table VII is a qualitative comparison of the relational-hybrid approach to geographic information systems (think object-relational database management system (O-RDBMS)) and a pure object-oriented approach to geographic information systems (think object-oriented database management system (ODBMS)).

Data Format Standards

Raster Product Format. Raster Product Format (RPF) is a standard data structure and data exchange format standard for geospatial databases composed of rectangular arrays of pixel values (e.g. in digitized maps or images) in compressed or uncompressed form. Raster Product Format (RPF) is intended to enable application software to use the data directly

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[101] "Oops!" The Economist, 28 February 1998, 83.
[102] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 51.

without further manipulations or transformation. Raster Product Format (RPF) defines a common format for interchange of raster data between producers and users of the data.[103]

Vector Product Format. Vector Product Format (VPF) is a standard format, structure, and organization for large geographic databases that are based on a georelational data model and are intended for direct use. Vector Product Format (VPF) defines the format of data objects, and the georelational data model provides a data organization within which software can manipulate the Vector Product Format (VPF) data objects. Vector Product Format (VPF) allows application software to read data directly without prior conversion to an intermediate form. Vector Product Format (VPF) is designed to be compatible with a wide variety of applications and products.[104]

Text Product Standard Format. The National Imagery and Mapping Agency (NIMA) is converting all of its nautical publications into digital products in a standard format called Text Product Standard (TPS). The plans are to make digital publications available on compact disk – read only memory (CD-ROM) and via the Internet.

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[103] Department of Defense, Military Standard: Raster Product Format, MIL-STD-2411, (Washington: 06 October 1994) 1.
[104] National Imagery and Mapping Agency, "Interface Standard for Vector Product Format" Military Standard VPF MIL-STD-2407, 18 July 1996 <http://164.214.2.59/publications/specs/printed/VPF/vpf.html> 12 February 1999.

CHAPTER VII

BRIDGING THE GAP – FROM ABSTRACT TO SUBSTANCE

Geographical Information System

> The history of using computers for mapping and spatial analysis shows that there have been parallel developments in automated data capture, data analysis, and presentation in several broadly related fields....Military applications have overlapped and even dominated several of these mono-disciplinary fields. Consequently there has been much duplication of effort and a multiplication of discipline specific jargon for different applications in different lands. This multiplicity of effort in several initially separate, but closely related fields has resulted in the emergence of the general purpose [Geographical Information System].[105]

Geographical Information System (GIS) is a generic term referencing "a system of computer software programs and equipment that is used to acquire, store, manipulate, analyze, and display spatial data."[106] Burrough and McDonnell define a Geographical Information System in terms of toolbox-based definitions, database definitions, and organization-based definitions. The development of Geographical Information Systems has produced "spatial information handling and mapping tools" enabling "a marriage between remote sensing, earth-bound survey, and cartography."[107] Geographical Information Systems provide "both an archive of spatial data in digital form and a tool for exploring the interactions between process and pattern in spatial and temporal phenomena."[108]

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[105] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 8.

[106] National Imagery and Mapping Agency, Military Handbook: Glossary of Mapping, Charting, and Geodetic Terms, MIL-HDBK-850, 21 January 1994, <http://164.214.2.59/publications/specs/printed/MCG_TERMS/E_L.doc> (22 February 1999).

[107] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 6.

[108] Ibid., 36.

A core capability of any Geographic Information System is data transformation.

Transformations can operate on the spatial, topological, and the non-spatial aspects of the data, either separately or in combination. Many of the transformations, such as those associated with scale changing, fitting data to new projections, logical retrieval of data, and calculation of areas and perimeters are of such general nature that one should expect to find them in every kind of GIS in one form or another. Other kinds of manipulation may be extremely application specific....[109]

Geospatial Information and Services

Geospatial Information and Services (GI&S) is neither a product nor a system but rather a concept for the collection, information extraction (production), storage (archiving), dissemination, and exploitation of information about the earth.[110] In other words, it is the concept integral to the management and processes associated with geospatial information.

Geospatial Information and Services (GI&S) "aids the commander in visualizing the battlespace, to effectively plan and execute military operations, to navigate, and to accurately target the adversary."[111] Appendix B, table VIII lists some of the things users will be able to do with resident exploitation capabilities in conjunction with Geospatial Information and Services. The major components of the geospatial information services concept are illustrated in figure 12.[112]

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[109] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 14.
[110] Joint Chiefs of Staff, JTTP for Geospatial Information and Services Support to Joint Operations (Joint Pub 2-03) Final Coordination (Washington D.C.: February 20, 1998), I-1.
[111] Ibid., v.
[112] Ibid., I-2.
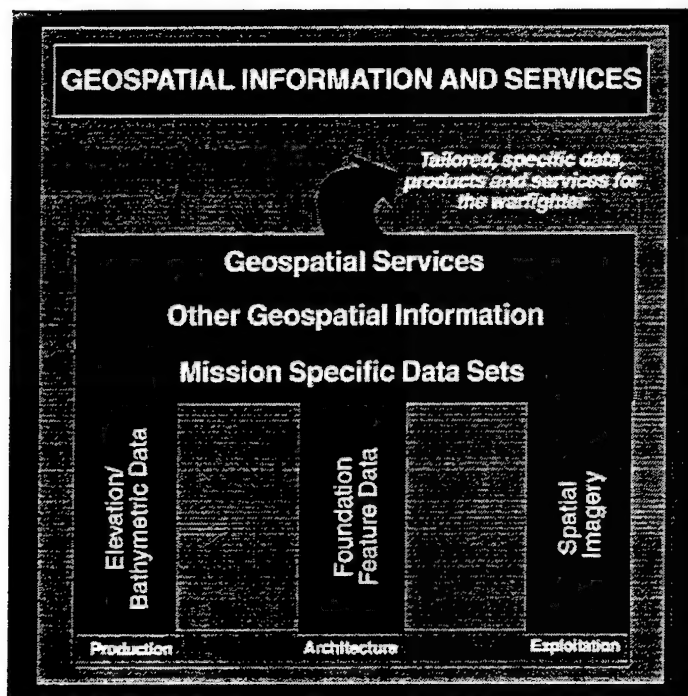
Figure 12

Geospatial Information and Services

Foundation Data. The Geospatial Information and Services concept identifies three major data elements (elevation and bathymetric data, foundation feature data, and spatial imagery) as the core pillars that make up Foundation Data.[113] Foundation Data is the same as the Geospatial Information Infrastructure Framework concept of Framework Information.

Elevation and Bathymetric Data. Digital Terrain Elevation Data (DTED) and the corresponding Digital Bathymetric Database (DBDB) for ocean floor depths provide a three-dimensional view of the mission space.[114]

Foundation Feature Data. "Foundation feature data are those key natural or manmade features which are represented in a vector file as a point, line, polygon, or text....[Features] include transportation and surface drainage networks, vegetation,

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[113] The Geospatial Information Infrastructure Master Plan identifies the types of information that make up the Foundation as follows: orthorectified monoscopic and stereoscopic imagery, such as Controlled Image Base (CIB) and Digital Point Positioning Data Base (DPPDB); digital elevation data (Digital Terrain Elevation Data Level 2); hydrographic/bathymetric information from the Hydrographic Source Assessment System (HYSAS) and from Digital Nautical Charts (DNCs); geophysical data such as gravity, and magnetics; nautical and aeronautical navigation safety information; and selected feature information. These types of data make up the GI&S classes identified above.

built-up areas, international boundaries, and selected spot elevation data. Many of these features contain attributes which further characterize information associated with the feature. For example, a...road would be depicted as a line and would carry attributes which describe its location, surface material, and operational status."[115]

Spatial Imagery. "The global spatial imagery layer will be composed of a seamless mosaic of ortho-rectified, black and white, high resolution (5 meter ground sample distance or better) satellite imagery....Currently, the major source for geospatial data is visible spectrum imagery provided by national intelligence systems".[116]

Foundation data will be available on a near-worldwide basis to support strategic planning and will support three-dimensional visualization and some analytical operations.[117] It is mission independent and relatively stable background information, or has in-place maintenance program (e.g., navigation safety information to ensure currency). Foundation data is specification compliant and consists of standard coverages of known accuracy and quality, geopositioned to a common horizontal datum (WGS-84) and known vertical datums.[118] "Foundation Data serves as the base for densification and for addition of new categories of information...such as additional imagery and imagery intelligence data."[119]

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[114] Joint Chiefs of Staff, JTTP for Geospatial Information and Services Support to Joint Operations (Joint Pub 2-03) Final Coordination (Washington D.C.: February 20, 1998), I-2.
[115] Ibid., I-2, I-3.
[116] Ibid., I-3, I-7.
[117] Ibid., I-2, I-3.
[118] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 25.
[119] Ibid.

Mission Specific Data Sets. Mission Specific Data Sets (MSDS) is data that enhances or builds on Foundation Data to meet specific operational needs.[120] Sources include higher resolution controlled imagery, elevation, and/or depth information and vector features needed to meet defined mission requirements. Digital Nautical Charts (DNC), Digital Terrain Elevation Data (DTED), Digital Bathymetric Data Base (DBDB), and digitized raster graphics, are Mission Specific Data Set (MSDS) examples of digital data in vector product format (VPF) or raster product format (RPF). Notice to Mariners, Sailing Directions, and country studies, are examples of publications and bulletins textual data in textual product standard (TPS).

Mission Specific Data Sets (MSDS) "are produced to satisfy validated area requirements for standard products as well as for standard coverages of geospatial information. Geospatial information specifications are standardized across each mission to ensure interoperability and an integrated view of the mission space." Mission Specific Data Sets (MSDS) information can be used by the National Imagery and Mapping Agency (NIMA), intelligence agencies, other government activities, and the warfighter to create specific data products for computer applications or to create hardcopy maps and charts.[121]

Qualified Data. "Qualified Data includes other data sets of known quality and accuracy that have not been integrated, or deconflicted, with Foundation Data and MSDS [Mission Specific Data Sets]." Qualified Data can come from many sources, including the National Imagery and Mapping Agency (NIMA), the Joint Warfare Analysis Center (JWAC), national and international government databases, commercially available products

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[120] Further densification of Foundation Data will be performed to support current operations, existing operation plans (OPLANs), training, and system development.
[121] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 27.

and databases[122], and user provided value added-data. "The assessment [for these other data sets is] based on established standards for accuracy, currency, resolution, content, and format."[123]

Value-added Data. "Value-adding is the process by which both the producer and the user of geospatial data constantly update geospatial data with current information."[124] Geospatial Information and Services "will manage the submission of geospatial information by users and producers. NIMA will accept value-added data from certified producers for incorporation into the Framework as Qualified Data. Data received from non-certified producers will be posted as unqualified geospatial data. Follow-on validation and incorporation into the Framework will be based on urgency to mission requirements and/or safety of navigation. The catalog will be updated to reflect the availability of new information that may be needed immediately by other users. The value-added data may also serve as a timely source of current information to support the production or update of Foundation Data and MSDS [Mission Specific Data Sets]."[125]

Metadata. Metadata is a common set of terms and definitions to use when documenting geospatial data that describes the content, quality, condition, and other characteristics of data.[126] Metadata, or data about data, is data that enables the user to better understand the characteristics of the geospatial data information that is available. "When

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[122] NIMA is the procurement and brokering agent for commercially available geospatial information.
[123] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 28.
[124] Joint Chiefs of Staff, JTTP for Geospatial Information and Services Support to Joint Operations (Joint Pub 2-03) Final Coordination (Washington D.C.: February 20, 1998), I-9.
[125] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 46-47.
[126] Federal Geographic Data Committee, Metadata. <http://www.fgdc.gov/metadata/metadata.html> (13 January 1999).

used in conjunction with application tools, it allows the intelligent integration of mission information from multiple sources with Framework Information."[127,128,129]

Geospatial Services. Geospatial Services provide an interface between Framework Information and the user environment. The services equip the user with the ability to access, retrieve and exploit the data needed to support a specific mission. Geospatial Information and Services and the Geospatial Information Infrastructure Framework offer the benefits listed in appendix B, table IX.

A catalog of Framework Information and useful "unqualified" geospatial data "will serve as a gateway to the information held by the both the producers and users in the infrastructure. Connectivity will be provided through an 'Internet-like' browser. Framework Services and the metadata contained in the catalog will support the user's ability to search, discover, retrieve and/or order the necessary geospatial information....Framework Services will provide connections with other gateways to facilitate access to..." data sources of other "unqualified" geospatial data.[130]

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[127] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 28.

[128] The Federal Geographic Data Committee (FGDC) recently adopted a content standard for metadata. This standard provides a consistent approach and format for the description of data characteristics. The standard provides a way for data users to know: what data are available, whether the data meet their specific needs, where to find the data, [and] how to access the data. Metadata standards will increase the value of such data by facilitating data sharing through time and space. According to an Executive order signed by President Clinton on April 11, 1994, all Federal agencies will begin to use this standard to document newly created geospatial data as of January 1995.

[129] The metadata standard is simply a common set of terminology and definitions that describe geospatial data, including the data elements, by the following topics: Identification Information, Data Quality Information, Spatial Data Organization Information, Spatial Reference Information, Entity and Attribute Information, Distribution Information, and Metadata Reference Information. A brief description of each of these topics can be found in the Metadata Factsheet. <http://www.fgdc.gov/metadata/metadata.html>.

[130] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 45-46.

Key concepts to successful Geospatial Information and Services (GI&S) support are streamlined flows of information, joint interoperability,[131] security,[132] and the provision for pull-down geospatial information tailored to the needs of the operational forces.[133]

How Will Users Interact with Geospatial Information and Services?

Resident exploitation capabilities and Geospatial Information and Services (GI&S) are used to fuse locally generated information and information from other sources with the Framework to created an integrated view of the mission space.[134] The Geospatial Information Infrastructure (GII) "will consist of a virtual network of information libraries and local data stores. Framework Information will be available from the National Imagery and Mapping Agency (NIMA) information libraries. Subsets of the information will be located at distributed regional libraries and local data stores to facilitate access; provide security; reduce wide area communication requirements; and provide for local data optimization as well as data fusion. Where Framework Information is held by a combatant command covering an area of responsibility (AOR) or area of interest (AOI), the command would automatically be sent updates of Framework Information. The combatant commander is responsible for the

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[131] Interoperability is the capability of people, organizations, and equipment to operate effectively together, sharing information so that it can be used across domains. Interoperability must be achieved across essential interfaces through common data models, exchange standards, and approved applications. The Geospatial Information Infrastructure (GII) will contribute to interoperability by providing a sharable global information set of logically consistent information, captured to standard definitions and rules, on a common geometry, of sufficient reliability to be the basis for all future intensification. It will also support the development of approved interoperable applications and standard applications interfaces.

[132] Providing for the protection and control of critical geospatial data are information warfare issues which must be addressed not only at the technology level, but at the policy and doctrine level as well. In the near term separate systems at specific security levels should be viewed as the norm due to indications that true multi-level security systems will not be available until early in the next century. At a minimum, fire walls and other security mechanisms (e.g., user profiles and metadata content) will be used to permit a "read down" capability for classified systems. Such a capability will permit users of the more restricted system to retrieve data from the lower classification system; thereby avoiding the costs of storing, administering and maintaining multiple copies of the data for security reasons.

[133] Joint Chiefs of Staff, JTTP for Geospatial Information and Services Support to Joint Operations (Joint Pub 2-03) Final Coordination (Washington D.C.: February 20, 1998), IV-3.

[134] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 29.

distributed regional library, or local data store, data administration and management to include access control, backups, management of local data and local media, performance tuning, and capacity management. The combatant commander is also response for the management of the local database and for incorporation and maintenance of "unqualified" geospatial data.[135]

"There is no existing multilevel security system to facilitate dissemination of disclosable and releasable information to US, allied, and/or coalition operational commanders."[136] "Services and commands must develop the architecture and connectivity needed to disseminate Framework Information and Services below the Unified Command/Joint Task Force level."[137] Combatant commands and subordinate Joint Force Commanders can request that geospatial data be either disclosed or released to coalition and/or allied nations as necessary.

What Is The Relationship Between The Geospatial Information Infrastructure Framework And Geospatial Information And Services?

The Geospatial Information Infrastructure (GII) Framework, Geographical Information Systems (GIS) and Geospatial Information and Services (GI&S) concepts have a lot in common, but they are not the same things.[138] They are overlapping concepts, which employ similar terms. Appendix A, figure 5 illustrates one way to view the relationship.

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[135] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 44-45.
[136] Joint Chiefs of Staff, JTTP for Geospatial Information and Services Support to Joint Operations (Joint Pub 2-03) Final Coordination (Washington D.C.: February 20, 1998), IV-1, 2.
[137] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 54-55.
[138] I reached this conclusion subsequent to phone conversations with NIMA officials whom varied on the relationship of the two concepts.

CHAPTER VIII

NIMA MARITIME PRODUCTS

The National Imagery and Mapping Agency (NIMA) is the principal and often sole supplier of mapping data and products that supports the U.S. Department of Defense, Intelligence Community, National Security Council, and other federal government agencies and departments. Appendix B, table XI lists NIMA's existing products and appendix B, table XII lists NIMA's prototype products at the time of research.[139] Appendix B, table XIII lists some maritime paper products and NIMA's digital product equivalent.

The remainder of this chapter briefly describes the following NIMA products: Digital Nautical Chart (DNC®), Littoral Warfare Data (LWD), Tactical Ocean Data (TOD), World Vector Shoreline – Vector Product Format (WVS-VPF), and Geospatial Symbology.

Digital Nautical Chart

DNC®[140] is a relational database product, produced in the Vector Product Format (VPF) data structure standard.[141,142] The DNC® database supports Geographical Information Systems (GIS) applications such as mission planning, command and control, weapon systems, situation awareness, and portrays selected maritime significant physical features in a format suitable for computerized navigation to support electronic chart display systems.

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[139] NIMA's existing and prototype products, as well as subject material on topics ranging from coordinate system issues, to mapping, charting and geodetic data, to standardization and interoperability, to technical assistance available, is available on the world-wide-web at <http://164.214.2.54/guides/dtf/index.html>.

[140] US law prohibits the domestic copyrighting of data produced with government money. Additionally, NIMA wants to ensure that a commercial vendor does not copy the name. Therefore, a trademark or registration ensures you get official NIMA data.

[141] National Imagery and Mapping Agency, Digital Nautical Chart, January 06, 1999, <http://164.214.2.54/guides/dtf/dnc.html> (February 1, 1999).

[142] Navy and NIMA chose the VPF data structure over the raster product format (RPF) data structure because, in addition to VPF advantages presented earlier, the International Hydrographic Organization (IHO) had chosen vector as the approved format for Electronic Chart Display and Information System (ECDIS). Additionally, in order to have a seamless transition from land charts to maritime charts in the littoral environment, maritime charts would have to conform with land charts, which are in the VPF data structure.

DNC® does not meet the international Electronic Chart Display and Information System (ECDIS) standards. However, NIMA feels that DNC® meets the data content, functionality, and symbology requirements of International Hydrographic Organization (IHO) standards. Only the data format, which is transparent to the user, differs. NIMA has requested that the International Hydrographic Organization (IHO) endorse DNC® in Vector Product Format (VPF) as the equivalent to the internationally recognized "S-57" data based products.[143] MIL-D-89023 is the Department of Defense military specification for DNC®.[144]

DNC® data content and coverage are intended to closely replicate NIMA's and the National Ocean Service's (NOS) Harbor, Approach, Coastal, and General chart series.[145] Worldwide coverage will be available by the year 2002. The initial DNC® database will consist of 29 DNC® geographic regions, distributed on 29 compact disk – read only memory (CD-ROM) media, which will ultimately provide global marine navigation between 84 degrees North and 81 degrees South latitudes, as illustrated in appendix A, figure 6.[146] DNC® CD-ROM availability and status is available on the world-wide-web. For convenience, the most recent listing can be found in appendix B, table XIV.

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[143] National Imagery and Mapping Agency, "FAQs and Answers on DNC and Full Utility Navigation Demonstration (FUND) Software," DNC Frequently Asked Questions. 02 February 1999, <http://www.nima.mil/dnctest/FAQ.html> (03 February 1999).

[144] NIMA plans to begin converting the Digital Nautical Chart (DNC®) database from the 1993 VPF™ Standard (MIL-STD-600006) to the 1996 VPF™ Standard. This standard change will align the DNC® database with NIMA's other suite of VPF™ data products and thus provide inter operability. NIMA will begin to produce DNC® data sets based on the 1996 VPF™ Standard starting in early in FY99. Current DNC® data sets that have been released on CD-ROM that have been compiled using the 1993 VPF Standard will be updated using 1996 VPF™ Standard and subsequently reissued on CD-ROM in early FY99.

[145] With regards to operations, and operational law related issues, VPF data is registered using a geographic coordinate reference system, with the World Geodetic System 1984 (WGS-84) as the horizontal (latitude/longitude) datum. Nautical Charts utilize various vertical (height) references for different features, as follows: Topographic features - Mean Sea Level or a High Water datum; Shoreline - a high water line; and Hydrographic features - a low water tide level called Sounding Datum or Hydrographic Datum.

[146] National Imagery and Mapping Agency, "Digital Nautical Chart (DNC) Public Page" Digital Nautical Chart, 28 January 1999, <http://164.214.2.59/dncpublic> (3 February 1999).

DNC®s consist of data partitioned into libraries[147] based upon the scale of source charts. Concepts for the future will require us to reorient our thinking from individual chart numbers to a data library concept. When the data library concept is taken to its logical conclusion, the user will specify the area of interest and scale desired. Never again will you have to cut and tape charts together.

DNC® database features are thematically organized as listed in appendix B, table XV. "Users can define queries to call up desired or customized information. For example, a ship's draft or keel depth for a submarine can be identified so that a safety zone can input to alert the navigator to a potential danger or unsafe water depth."[148]

Digital Nautical Chart (DNC®) is currently updated by reissuing compact disk – read-only-memory (CD-ROM) media. However, "in December 1996 the Navy approved electronic file replacement, in VPF, as the process for updating"[149] VPF products, such as DNC®; a concept NIMA calls VPF Digital Update (VDU). "Ultimately, NIMA will send these updates to the Navy electronically over SIPRNET/NIPRNET and standard communications circuits."[150] "Until an updating system is in place, and NIMA's GEOSYM symbology is implemented, DNC® is not authorized for shipboard electronic chart navigation....When DNC® is certified for safe navigation, Navy ships will utilize DNC® as the primary means for shipboard navigation."[151] The U.S. Coast Guard has no such policy.

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[147] The DNC libraries are termed Harbor > 1:50,000; Approach 1:25,000-1: 100,000; Coastal 1:75,000 - 1: 500,000; and General < 1:500,000.

[148] National Imagery and Mapping Agency, "FAQs and Answers on DNC and Full Utility Navigation Demonstration (FUND) Software," DNC Frequently Asked Questions. 02 February 1999, <http://www.nima.mil/dnctest/FAQ.html> (03 February 1999).

[149] NIMA has experienced problems with electronic file replacement in VPF. However, they have had success with updating databases using object-oriented technology.

[150] Zdenka S. Willis, CDR, USN, and others, Geospatial Information & Services Maritime Navigation Handbook, Version 2.0, 20 April 1998. <http://oceanographer.navy.mil/gi&s_hbk.html> (11 January 1999).

[151] For information on DNC® recommend NIMA's DNC® Homepage at <http://www.nima.mil/dnctest>, NIMA's DNC® write-up in Digitizing the Future Guides at <http://164.214.2.54/guides/dtf/dnc.html>, or the

Littoral Warfare Data

Littoral Warfare Data (LWD) is a vector-based digital product relevant to amphibious operations and mine warfare. Littoral Warfare Data is a data set that contains feature, sounding, and attribute information that portrays selected marine and coastal features in littoral regions.[152,153,154] It is designed for use in conjunction with the Digital Nautical Chart (DNC®).

Tactical Ocean Data

Tactical Ocean Data (TOD) is a vector-based digital product that portrays the seafloor[155] in a format suitable for computerized subsurface navigation and Geographic Information System (GIS) applications. Tactical Ocean Data (TOD) is based on the feature content of the Bathymetric Naval Planning Chart (BNPC)[156] but will also contain Bottom Contour (BC) and other classified products to support submarine operations."[157] Tactical Ocean Data (TOD) is organized into thematic coverages, or layers, that correspond to the

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Oceanographer of the Navy's Geospatial Information and Services Maritime Navigation Handbook at <wysiwyg://17/http://oceanographer.navy.mil/gi&s_hbk.html>.

[152] LWD is the combined, deconflicted data content of a group of available standard NIMA products. These include but are not limited to: Digital Topographic Data (DTOP), Digital Nautical Chart (DNC), Digital Terrain Elevation Data (DTED), Digital Bathymetric Data Base (DBDB), and a special high resolution data set.

[153] LWD is organized into thematic coverages or layers. The data library contains the following 22 coverages: Tile Reference, Aeronautical, Coastline/Boundaries, Data Quality, Database Reference, Depth Information, Elevation, Ground Obstacles, Ground Transportation, Hydrographic Aids to Navigation, Hydrographic Dangers, Hydrographic Limits, Industry, Inland Water, Magnetics, Ocean Environment, Physiography, Ports and Harbors, Population, Utilities, Vegetation, and Library Reference.

[154] For information on Littoral Warfare Data (LWD) recommend Oceanographer of the Navy's Geospatial Information and Services Maritime Navigation Handbook at <wysiwyg://17/http://oceanographer.navy.mil/gi&s_hbk.html>.

[155] particularly in areas deeper than 183 meters (100 fathoms).

[156] National Imagery and Mapping Agency, "Tactical Ocean Data," VPF Products, 20 March 1998, <http://164.214.2.59/vpfproto/tod1.htm> (12 February 1999).

[157] Zdenka S. Willis, CDR, USN, and others, Geospatial Information & Services Maritime Navigation Handbook, Version 2.0, 20 April 1998. <http://oceanographer.navy.mil/gi&s_hbk.html> (11 January 1999).

coverages in Digital Nautical Chart.[158,159,160] It is designed for use in conjunction with the

Digital Nautical Chart.(DNC®).

World Vector Shoreline – Vector Product Format

The World Vector Shoreline (WVS) database is being restructured to be Vector

Product Format (VPF) compliant. World Vector Shoreline – Vector Product Format (WVS-

VPF) is slated to be part of the data sets used by command and control systems for various

situation/map displays. Content includes shoreline information, country boundaries, some

general bathymetric coverage, and information on international maritime limits.[161,162]

Geospatial Symbology

Vector data has no symbol set of its own. Therefore, the National Imagery and

Mapping Agency (NIMA) developed a symbol set to be used in conjunction with Vector

data, which NIMA calls Geospatial Symbology (GeoSym™).[163] Geospatial Symbology

conforms with international standards set by the International Hydrographic Organization

(IHO) for nautical charts.[164]

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[158] National Imagery and Mapping Agency, "Tactical Ocean Data," VPF Products, 20 March 1998, <http://164.214.2.59/vpfproto/tod1.htm> (12 February 1999).

[159] Tactical Ocean Data thematic coverages include: Aeronautical, Earth Cover, Environment, Hydrography, Limits, Obstructions, Data Quality.

[160] For information on Tactical Ocean Data recommend Oceanographer of the Navy's Geospatial Information and Services Maritime Navigation Handbook at <wysiwyg://17/http://oceanographer.navy.mil/gi&s_hbk.html>.

[161] The coastal shoreline feature is derived from Digital Landmass Blanking data, supplemented by Operational Navigation Charts (ONC) and Tactical Pilotage Charts (TPC). Other features are derived from the Digital Bathymetric Database and the Joint Operations Graphic, ONC, and TPC paper products. Offshore territorial boundaries are derived from baselines found in DoD 2005.1M, the Maritime Claims Reference Manual. Mean High Water is the shoreline reference; Mean Sea Level is the reference for hydrographic depths.

[162] For information on World Vector Shoreline – Vector Product Format recommend NIMA's write-up in Digitizing the Future Guides at <http://164.214.2.54/guides/dtf/wvs_vpf.html>, or Oceanographer of the Navy's Geospatial Information and Services Maritime Navigation Handbook at <wysiwyg://17/http://oceanographer.navy.mil/gi&s_hbk.html>.

[163] Although the symbol set is physically located on a different CD-ROM than the dataset, many of the software packages load the symbol set onto the hard drive for your use.

[164] Zdenka S. Willis, CDR, USN, and others, Geospatial Information & Services Maritime Navigation Handbook, Version 2.0, 20 April 1998. <http://oceanographer.navy.mil/gi&s_hbk.html> (11 January 1999).

CHAPTER IX

GEOSPATIAL INFORMATION AND SERVICE TOOLS

Geospatial applications fall into two categories, shared geospatial processing services and mission specific applications.[165] This chapter will only deal with shared geospatial processing services.

> Shared geospatial processing services support the basic functions of data access, manipulation and display. They provide a "tool kit" of functions such as those found in a commercial geographic information system [GIS] software product. For DoD [Department of Defense] users in the DII [Defense Information Infrastructure] environment, the Joint Mapping Tool Kit (JMTK) currently provides a suite of shared geospatial processing services.[166]

Vector Product Format (VPF) databases can be accessed and viewed by both government and commercially available software. Government off-the-shelf software (GOTS) programs include Full Utility Navigation Demonstration (FUND), and NIMA's Mapping Charting and Geodesy (MC&G) Utility Software Environment (NIMAMUSE). Commercially off-the-shelf software (COTS) available includes ESRI's ARCVIEW and ARCINFO[167], among others. The remainder of this chapter will look at NIMA's, FUND, NIMAMUSE, and JMTK software applications.

Full Utility Navigation Demonstration

Full Utility Navigation Demonstration (FUND) was developed to demonstrate and help familiarize the Navy with the use of the Digital Nautical Chart (DNC®) database in an Electronic Chart Display and Information System (ECDIS) environment.

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[165] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 48.

[166] Ibid.

[167] Presently, ESRI's software applications, ARCVIEW and ARCINFO, are widely used amongst governmental agencies due to their ability to support analysis by relating and integrating different databases, as well as their ability to tailor products and export the desired results in common briefing formats.

Full Utility Navigation Demonstration (FUND) software was designed for stand-alone personal computers and currently operates on Windows 95 or 98 platforms. It utilizes the DNC® database directly with no pre-processing required. Future versions of Full Utility Navigation Demonstration (FUND) software will support NIMA's DNC® companion products, Tactical Ocean Database (TOD) and Littoral Warfare Database (LWD).[168,169]

Full Utility Navigation Demonstration (FUND) software meets most of the International Maritime Organization (IMO) and International Hydrographic Organization (IHO) performance standards. Full Utility Navigation Demonstration (FUND) software is capable of displaying all chart information necessary for safe and efficient navigation and allows for Differential Global Positioning System (DGPS) input. "It is demonstration GOTS software and has not been certified as 'safe for navigation'."[170]

NIMA Mapping, Charting, and Geodesy Utility Software Environment

The National Imagery and Mapping Agency's (NIMA's) Mapping, Charting, and Geodesy (MC&G) Utility Software Environment, NIMAMUSE™ is a self-contained set of computer programs and computer utilities designed to work with NIMA's MC&G data and information. NIMAMUSE™ is designed to be loaded on to and run from IBM personal computers running Windows, Sun, Hewlett-Packard, and Silicon Graphics operating systems.[171]

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[168] Robert Greer, SPAWAR, Telephone conversation with FUND project manager, 14 December 1998.
[169] Robert Greer, <fund@olga.spawar.navy.mil> "Full Utility Navigation Demonstration (FUND)."
15 December 1998. Office communication. (15 December 1998).
[170] Zdenka S. Willis, CDR, USN, and others, Geospatial Information & Services Maritime Navigation
Handbook, Version 2.0, 20 April 1998. <http://oceanographer.navy.mil/gi&s_hbk.html> (11 January 1999).
[171] National Imagery and Mapping Agency, NIMAMUSE 2.1, 08 October 1998,
<http://164.214.2.59/geospatial/SW_TOOLS/NIMAMUSE/> (03 February 1999).

NIMAMUSE[TM] provides users with three distinct activities. The user may build a

map, access and prepare NIMA digital data, and run specialty applications.[172] "Basic

exploitation includes the capability to import, annotate, and simultaneously display different

vector and raster products...fused together over the same area."[173]

Vector Product Format View

Vector Product Format (VPF) View (VPFView) is the NIMAMUSE[TM] application

that allows you to browse, display, and perform spatial queries on NIMA's digital vector data

in Vector Product Format (VPF). VPFView reads a VPF product, produces user-defined

views, and displays those views. VPF data to be displayed are selected by features, which

are subsequently collected and saved into structures called views.[174] "You can select data

from one or more databases for display by region, feature, or group of related data types.

You don't have to load or convert the data: simply read it directly from the media (CD-ROM,

hard drive, or diskette). It is not a Geographic Information System (GIS), so it has no

analytical capability other than viewing and zooming data features."[175]

<u>Joint Mapping Tool Kit</u>

Joint Mapping Tool Kit (JMTK) is a collection of Application Programming

Interfaces (APIs) that enable mission applications to interface with geospatial information.

For example, JMTK Version 4.0 has APIs to perform Synthetic Aperture Radar (SAR), Low

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[172] These activities are supported by nine major application programs, entitled: Fusion; Raster Importer; Vector Importer; Perspective Scene; Line of Sight; Datum Transformation & Coordinate Conversion, DTCC4; VPFView 2.1, REALTIME; and REPORT.
[173] Zdenka S. Willis, CDR, USN, and others, <u>Geospatial Information & Services Maritime Navigation Handbook</u>, Version 2.0, 20 April 1998. <http://oceanographer.navy.mil/gi&s_hbk.html> (11 January 1999).
[174] National Imagery and Mapping Agency, "VPFView," <u>VPFView 2.1</u>, <http://164.214.2.59/geospatial/SW_TOOLS/NIMAMUSE/dist/vpfview/docs/vpfvi.../vpfview.htm> (03 February 1999).
[175] Zdenka S. Willis, CDR, USN, and others, <u>Geospatial Information & Services Maritime Navigation Handbook</u>, Version 2.0, 20 April 1998. <http://oceanographer.navy.mil/gi&s_hbk.html> (11 January 1999).

Level Light Television (LLLTV), Forward Looking Infrared (FLIR), and Radar sensor prediction calculations.

Joint Mapping Tool Kit (JMTK) is not a stand-alone capability; it is embedded in other applications, and is accessed through the Application Programming Interfaces (APIs). Joint Mapping Tool Kit (JMTK) is grounded in the concepts of interoperability and functionality[176], which is why it is, and will remain, a work in progress. Joint Mapping Tool Kit (JMTK) is platform independent and will run on Solaris, HP UNIX, and Windows NT computers. See the Joint Mapping Tool Kit (JMTK) home page[177] for the latest on development status and requirements for present and future build plans.

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[176] Mel Wagner, former National Imagery and Mapping Agency Joint Mapping Tool Kit Program Manager, telephone conversation with former program manager, 28 January 1999.

[177] The Joint Mapping Tool Kit (JMTK) home page is at <http://www.jmtk.org>

CHAPTER X

MORE ON STANDARDS AND SYSTEMS

Safety of Life at Sea

Chapter 5, regulation 20 of the Safety of Life at Sea (SOLAS) convention, on

"nautical publications" requires that all ships must carry adequate and up-to-date charts,

sailing directions, list of lights, notices to mariners, tide tables, and other nautical

publications necessary for the voyage they are undertaking.[178,179] "Today this is satisfied with

paper charts but the IMO [International Maritime Organization] in November 1995 modified

this to allow ECDIS [Electronic Chart Display and Information System] equivalency....The

Navy traditionally conforms to these same standards although not required to do so by

law."[180]

Electronic Chart Display and Information System

The Electronic Chart Display and Information System (ECDIS) performance

standard, adopted by the International Maritime Organization (IMO) under Resolution A817

in November 1985,[181] noted "that up-to-date charts required by SOLAS regulation V/20 can

be provided and displayed electronically on board ships by electronic chart display and

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[178] International Maritime Organization, International Convention for the Safety of Life at Sea. <http://www.imo.org/imo/focus/safnav/safenav2.htm> (05 December 1998).
[179] The first and most far-reaching convention adopted by the IMO was the Convention of Safety of Life at Sea (SOLAS) in 1960. This convention actually came into force in 1965, replacing a version first adopted in 1948. Because of the difficult process of bringing amendments into force internationally, none of the subsequent amendments became binding. To remedy this situation, a new convention was adopted in 1974, and became binding in 1980. The Convention in force is known as SOLAS 1974. Chapter V of SOLAS is currently being completely revised and will enter into force on 01 July 2002. Changes to SOLAS Chapter V include requirements for navigational aids and equipment, taking into account advances in technology.
[180] Zdenka S. Willis, CDR, USN, and others, Geospatial Information & Services Maritime Navigation Handbook, Version 2.0, 20 April 1998. <http://oceanographer.navy.mil/gi&s_hbk.html> (11 January 1999).
[181] Performance standards for ECDIS were adopted in order to ensure the operational reliability of such equipment, and to ensure that the information provided and displayed electronically is at least equivalent to that of up-to-date charts; and, when also provided and displayed, other nautical publications. Adopting performance standards was meant to avoid, as far as practicable, adverse interaction between ECDIS and other shipborne navigational and communication equipment.

information systems (ECDIS), and that the other nautical publications required by the regulation V/20 may also be provided and displayed."[182] Characteristics of ECDIS compliant systems are listed in appendix B, table XVI.

ECDIS is defined by the International Maritime Organization (IMO) as a system which is compliant with the IMO Performance Standard for ECDIS. An ECDIS system "refers to a specialized geographic database and computer system. The database contains digitized nautical charts provided by a government hydrographic agency...and formatted according to an international standard [originally] referred to as "DX-90" and now referred to as "S-57."[183] Systems which are not 'IMO compliant' are categorized as Electronic Chart Systems (ECS)."[184]

"By superimposing electronic chart, ship position, and RADAR on one display, ECDIS has the potential to improve the accuracy of navigation, increase awareness of dangerous conditions, and reduce the mariner's workload."[185] The U.S. Coast Guard "has shown consistently that ECDIS can provide equivalent or greater safety than that provided by the use of paper chart and more traditional methods of navigation."[186,187]

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[182] Chief of Naval Operations, "International Maritime Organization Resolution A.817(19): Performance Standards for Electronic Chart Display and Information Systems." U.S. Navy Electronic Chart Display and Information System Policy, Serial N00/8U5000076 of 17 March 1998,(Washington, D.C.).

[183] The U.S. Navy has developed a similar standard called Electronic Chart Display and Information Systems – Navy or ECDIS-N, which is similar to ECDIS, but uses Vector Product Format (VPF) in lieu of S-57.

[184] Irene M. Gonin and others, Electronic Chart Display and Information System (ECDIS) Test and Evaluation, Summary Report, U.S. Coast Guard Research and Development Center, Report No. CG-D-20-97. (Groton, Connecticut: December 1996). ES-1.

[185] Ibid.

[186] Ibid., ES-3-4.

[187] Coast Guard test and evaluation, of navigation systems that are IMO compliant of ECDIS performance standards, concluded the following. "ECDIS did significantly improve overall track keeping performance, and that there were no significant differences in navigational performance between mariners with varying levels of experience when navigating with ECDIS....ECDIS with automatic positioning decreased the mean cross-track distance to approximately one third of what it was with conventional methods....The ECDIS by creating a real-time visualization of the ship's position in relation to its surroundings, aids the mariner....ECDIS can give the mariner more time for such tasks as lookout and collision avoidance, when they are most important....ECDIS with automatic positioning decreased both the mean workload for navigation and the mean reported proportion of time spent on navigation. It was also shown that with the decrease in proportion of time spent on navigation

<u>Electronic Chart Display and Information System – Navy</u>

Electronic Chart Display and Information System – Navy (ECDIS-N) is the Navy's

performance standard for ECDIS. In the context of a performance standard, ECDIS-N

"means a navigation information system which, with adequate back-up arrangements, can be

accepted as complying with up-to-date chart required by Navy Instructions, by displaying

selected information from a system [digital] navigational chart (SDNC) in VPF with

positional information from navigation sensors to assist the mariner in route planning and

route monitoring, and by displaying additional navigation related information if required."[188]

ECDIS-N compliant systems should be capable of the functionality listed in appendix B,

table XII.[189,190]

The Chief of Naval Operations letter on U.S. Navy Electronic Chart Display and

Information System Policy "directs a Navy transition from navigation by means of paper

charts to navigation by means of digital charts within the ECDIS-N standards. This policy

promulgates the minimum ECDIS-N standards…and delineates specific responsibilities of

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using ECDIS with automatic positioning, there was a corresponding increase in the proportion of time spent on look out and collision avoidance. In the mariner's view, this shift represented an increase in safety. [Gonin, 1996]

[188] Chief of Naval Operations, "U.S. Navy Electronic Chart Display and Information System Policy," Serial N00/8U5000076 of 17 March 1998,(Washington, D.C.).

[189] In the context of a performance standard, Electronic Navigational Chart (ENC) means the database, standardized as to the content, structure and format, issued for use with ECDIS-N by NIMA. The ENC contains all the chart information necessary for safe navigation, and may contain supplementary information in addition to that contained in the paper chart (e.g. sailing directions) which may be considered necessary for safe navigation. ENC defined for the U.S. Navy is DNC®. For Submerged safe navigation ENC is defined as DNC® and TOD.

[190] In the context of a performance standard, System Digital Nautical Chart (SDNC) means a database resulting from the direct read of the VPF products by ECDIS-N for appropriate use, updates to DNC via VDU, and other data added by the operator. It is the database that is actually accessed by ECDIS-N for the display generation and other navigational functions, and is the equivalent to an up-to-date paper chart. The SDNC may also contain information from other sources. The term SDNC is identical to the term SENC as defined for civil ECDIS, except that the data format is specified for SDNC.

OPNAV, Fleet Commanders in Chief, and Commander, Operational Test and Evaluation Force (COMOPTEVFOR)."[191]

U.S. Navy vessels are not required to comply with International Maritime Organization (IMO) resolutions. In setting standards in keeping with safe maritime operations, however, the Navy will follow Department of Defense (DoD) mandates to use commercial standards wherever possible.[192] Deviations from the civil guidance will be limited to those required for unique military applications and approved naval navigation and piloting procedures.[193,194]

The ECDIS-N performance standard addresses two issues that are of concern to all operators, back-up arrangements and power supply. With regards to power supply, the ECDIS-N performance standard says "it should be possible to operate ECDIS-N and all equipment necessary for its normal functioning when supplied by an emergency source of electrical power....Changing from one source of power supply to another, or any interruption of the supply for a period of up to 45 seconds, should not require the equipment to be re-initialized manually." With regards to back-up arrangements, the ECDIS-N performance standard says "adequate back-up arrangements should be provided to ensure safe navigation

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[191] Chief of Naval Operations, "U.S. Navy Electronic Chart Display and Information System Policy," Serial N00/8U5000076 of 17 March 1998, (Washington, D.C.).

[192] Using ECDIS as a foundation for the Navy's transition to electronic charts is a good idea, because the inventory of Navy vessels is just a drop in the bucket when compared to over 80,000 civil ships expected to use ECDIS. In conjunction with DoD's move to emphasize COTS software & hardware, it makes good business sense to use what's being developed for civil shipping. Secondly, these commercial standards have been in development for 10 years by all the maritime nations and have undergone rigorous testing around the world. These standards provide a good path for the Navy to safely transition from relying primarily on paper charts to utilizing digital charts and electronic systems. SMART SHIP showed that these commercial standards can work for the Navy with small modifications.

[193] Principally, these additions mandate the use of NIMA data, which differs slightly from the international vector data transfer format referenced in the IMO resolution, and support visual bearing and dead reckoning (neither is fully supported in civil shipping).

[194] Chief of Naval Operations, "U.S. Navy Electronic Chart Display and Information System Policy," Serial N00/8U5000076 of 17 March 1998, (Washington, D.C.).

in case of an ECDIS-N failure."[195] The ECDIS-N standard spells out the back-up capability

functional requirements and provides guidance on how this capability can be met. "In order

to ensure that safe navigation is not compromised in the event of ECDIS-N failure, overall

ECDIS-N system availability shall be equal to the availability of current navigation

procedures that use paper charts. Table II lists acceptable means of achieving this level of

availability.

Table II[196]

ECDIS-N Back-up Solutions

Dual, redundant ECDIS-N systems (primary and back-up) with a demonstrated availability equal to paper chart availability. (This can include redundancy in multiple servers and LAN configurations).
A primary ECDIS-N system with a NIMA paper chart to provide back-up capability.
A primary ECDIS-N system with the capability to print color charts at an acceptable size and scale. (Note – this presumes that policies are implemented to ensure that required paper back-up charts are printed prior to a voyage.

ECDIS –N with adequate back-up arrangements may be accepted, as complying with

up-to-date charts required by regulation V/20 of the 1974 SOLAS Convention.[197,198]

The Deputy Chief of Naval Operations for Resources, Warfare Requirements and

Assessments (N8), shall certify that ECDIS-N systems comply with the standards set forth in

the CNO's policy prior to authorizing use of ECDIS-N systems in lieu of paper charts. The

certification will be based on Operational Test and Evaluation results and implementation of

Integrated Logistics Support. (This does not preclude the use of ECDIS-N systems prior to

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[195] Chief of Naval Operations, "U.S. Navy Electronic Chart Display and Information System Policy," Serial N00/8U5000076 of 17 March 1998, (Washington, D.C.).
[196] Ibid.
[197] Ibid.
[198] Zdenka S. Willis, CDR, USN, and others, Geospatial Information & Services Maritime Navigation Handbook, Version 2.0, 20 April 1998. <http://oceanographer.navy.mil/gi&s_hbk.html> (11 January 1999).

certification, provided that use is restricted to situational awareness only.[199] Uncertified

ECDIS-N systems may not be used in lieu of paper charts); The Oceanographer of the Navy

(N096) shall establish and maintain minimum standards for ECDIS-N and review future IMO

resolutions and standards, and validate all new Geospatial Information & Services (GI&S)

requirements and coordinate the development of new standard DoD products. Fleet

Commanders in Chief shall serve as certifying authority for areas where ECDIS-N can be

employed in lieu of paper charts. The policy authorizes Fleet Commanders to approve the

use of ECDIS-N within geographical areas covered by Geospatial Information & Services

(GI&S) products that meet ECDIS-N standards and updates.[200] The Navy will achieve

interoperability by mandating standards and functional requirements for ECDIS-N and

associated electronic charts as listed in appendix B, table XVIII. Appendix A, figure 7

illustrates how these concepts relate to key concepts presented earlier.

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[199] While the interim use of ECDIS-N systems for enhanced situational awareness is acceptable, U.S. Navy vessels may not use ECDIS-N systems in lieu of the requirement to maintain paper charts until the ECDIS-N systems are tested, certified, and approved for fleet introduction (initial operational capability) by the appropriate authority.
[200] Chief of Naval Operations, "U.S. Navy Electronic Chart Display and Information System Policy," Serial N00/8U5000076 of 17 March 1998,(Washington, D.C.).

CHAPTER XI

A NETWORK CENTRIC APPROACH

Object Vector Product Format

"In 1991, the US Navy…began investigating how object technology could improve its digital maps. This research led to the development of the Object Vector Product Format [OVPF], an object-oriented approach to viewing and editing digital maps and charts. By combining multiple relational databases into a single OO [object-oriented] database, OVPF [Object Vector Product Format] offers users such key advantages as the ability to immediately update and modify the content of the original data."[201]

First, the University of Florida's GeoPlan Center, under the Digital Mapping, Charting, and Geodesy Analysis Program (DMAP), developed an object-oriented prototype of the Digital Nautical Chart (DNC), called Object Digital Nautical Chart (ODNC). "ODNC could import directly from VPF flat file structure and had several useful features, such as direct feature updating capabilities and reduced access time."[202] "The OO [object-oriented] prototype, Object Digital Nautical Chart [ODNC], proved successful, and the team went on to develop object models and prototypes for three other VPF [Vector Product Format] products, World Vector Shoreline Plus [WVS+], Vector Smart Map, and Urban Vector Smart Map. The more general prototype, known as Object Vector Product Format [OVPF], could import any of NIMA's [National Imagery and Mapping Agency's] VPF products distributed on CD-ROM, then convert the data into an object format for display, query, and updating purposes."[203] Object Vector Product Format (OVPF) "can combine the previously separate

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[201] Kevin Shaw and others, "Managing the US Navy's First OO Digital Mapping Project", IEEE Computer, September 1996, 69.
[202] Ibid., 70.
[203] Maria Cobb and others, "An OO Database Migrates to the Web," IEEE Software, May/June 1998, 23.

database information into one database supporting feature-level manipulation, and then transform it back into the original relational-VPF [Vector Product Format] database file structure….[Further, Object Vector Product Format (OVPF)] can access and modify the information content of all four original relational databases to support spatial queries, update feature codes, and modify attributes and geometry."[204] "Research has shown that with an OO [object-oriented] approach, developers can feasibly manage even complex topology."[205]

The Object Vector Product Format (OVPF) project "expanded to include OO [object-oriented] models for NIMA's [National Imagery and Mapping Agency's] two other families of digital products, Raster Product Format [RPF] and Text Product Standard [TPS]."[206] A later development phase explored Object Database Management Systems (ODBMS), ObjectStore and GemStone, as high-performance repositories for spatial feature data.

Why use an Object Database Management System (ODBMS)? "As described above, Object Vector Product Format (OVPF) can function without a database management system. Relational tables are processed and information is brought into memory upon import of one or more coverages. Once in memory, disk resident data are never subsequently accessed. The advantage of this approach, besides its simplicity, is that the memory resident data are quickly accessible for manipulation, eliminating the need to perform costly disk access and table joins. The disadvantages are primarily: (1) the amount of data that can be imported for a single session is limited by the capacity of physical memory, and (2) data are not made available for concurrent access by multiple users; thus changes to the data made through the use of OVPF [Object Vector Product Format] are not readily apparent to others. The use of

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[204] Kevin Shaw and others, "Managing the US Navy's First OO Digital Mapping Project", IEEE Computer, September 1996, 70.
[205] Ibid., 72.
[206] Maria Cobb and others, "An OO Database Migrates to the Web," IEEE Software, May/June 1998, 23.

an ODMS [Object Database Management System] eliminates both of these concerns, as well as providing additional advantages. For example, with this approach, OVPF [Object Vector Product Format] is no longer limited by memory size for data import and viewing; data are simply stored in the database until needed, then brought memory for display or editing purposes. Additionally, geographic object level security and auditing can be readily managed. The function of any DBMS [Database Management System] is to provide persistent (maintained from session to session) storage of data, controlled access to the data, and backup and recovery capabilities, among others. Object-oriented DBMSs [Object Database Management System] provide these functions specifically for objects....While objects are generally considered to consist of both state (data) and behavior (procedures), ODBMSs [Object Database Management System] are typically concerned only with the storage of the state information."[207]

The Naval Research Laboratory integrated an Object Database Management System (ODBMS) as a layer to the Object Vector Product Format (OVPF) model. They were "able to migrate VPF [Vector Product Format] metadata and feature data to the ObjectStore repository, retrieve it via interactive spatial query, and then display the resulting map on a screen...."[208] Integrating an Object Database Management System (ODBMS) with Object Vector Product Format (OVPF) improved OVPF's overall performance "in the areas of data import, display, and querying....Aside from these improvements in the OVPF [Object Vector Product Format] model, the pure advantage of having a database management system is a gain in itself....Multi-user access and configuration control are provided to allow more use of

[207] Kevin Shaw and others, "Migration Process and Consideration for the Object-Oriented Vector Product Format to ObjectStore Database Management System," Object Databases in Practice Chapter 15 (London: Prentice Hall 1998), 236-237.

the data without having to maintain a copy of data on every user's computer and subsequently having to be concerned about consolidating the changes."[209]

The Naval Research Laboratory roadmap includes demonstrating the ability to pass raster objects in addition to the vector objects. Users "will have access to map objects from any platform that has a network-connected Web browser. This would let less capable client-side machines simulate the functionality of more powerful server machines. Future plans also include the ability of client users to modify data and pass the modifications back to the server for subsequent distribution. For example…one user could perform an action that affects either the geometry or attributes of a feature – for example, destroying part of a bridge – then have that information relayed back to the server so that collaborative models could be informed of the change….Web-based mapping repositories are clearly the future for both military and civilian mapping needs."[210]

Geospatial Information Database Format

The Naval Research Laboratory at Stennis, Mississippi, under the Digital Mapping, Charting and Geodesy Analysis Program (DMAP), has developed an object-oriented (OO) digital mapping database prototype, called the Geospatial Information Database (GIDB). The Geospatial Information Database (GIDB) object-oriented (OO) data model is derived from National Imagery and Mapping Agency's (NIMA's) Vector Product Format (VPF). It is, capable of importing any of the National Imagery and Mapping Agency's Vector Product Format data and converting the data into an object format for display, query, and updating purposes. This system has been extended to include object-oriented (OO) models for

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[208] Kevin Shaw and others, "Managing the US Navy's First OO Digital Mapping Project", IEEE Computer, September 1996, 72.

National Imagery and Mapping Agency's (NIMA's) two other families of digital products, Raster Product Format (RPF) and Text Product Standard (TPS).[211]

"The DMAP [Digital Mapping, Charting and Geodesy Analysis Program] Team has also investigated existing OO [object-oriented] technology that would allow the transfer and retrieval of data from the GIDB [Geospatial Information Database] over the internet."[212] Web-based Java client access the Geospatial Information Database (GIDB) database gives end users the ability to access and use NIMA [National Imagery and Mapping Agency] data quickly and efficiently. This will allow the functionality of more powerful server machines to be exhibited on less capable client machines. The Naval Research Laboratory has demonstrated an applet that allows any user with a Java-enabled web browser to access their Geospatial Information Database (GIDB) over the internet and display National Imagery and Mapping Agency (NIMA) map data.[213]

This latest technology will be demonstrated during the Marine Corps Warfighting Laboratory's experiment Urban Warrior. The demonstration will load an object-oriented Geospatial Information Database (GIDB) database onboard the U.S.S. Coronado for the area of interest. The database will then be updated from NIMA by sending objects (as opposed to whole files) over communication circuits. The success of this demonstration will demonstrate the ability to perform electronic updates of geospatial information while minimizing the requirements for communications bandwidth.

[209] Kevin Shaw and others, "Migration Process and Consideration for the Object-Oriented Vector Product Format to ObjectStore Database Management System," Object Databases in Practice Chapter 15 (London: Prentice Hall 1998), 251.

[210] Maria Cobb and others, "An OO Database Migrates to the Web," IEEE Software, May/June 1998, 27-30.

[211] Kevin Shaw and others, "Design of a Java Interface to a Smalltalk OO Mapping Database Utilizing CORBA" in Parallel and Distributed Computing and Systems: Proceedings of the Tenth IASTED International Conference ed. Yi Pan and others (Anaheim: IASTED/ACTA 1998), 60.

[212] Ibid., 60,62.

[213] Ibid., 62-63.

CHAPTER XII

CONCLUSIONS AND RECOMMENDATIONS

Solutions Sets within the Solution Space

A solution is the distribution of geospatial information products on compact disk – read only memory (CD-ROM) media. NIMA will soon be able to support this approach. However, this approach to updating geospatial information requires new CD-ROMs be produced and distributed.

A similar solution is to provide the bulk of geospatial information on CD-ROM and perform updates by electronic means. This is a useful approach for text data such as "Notice to Mariners." This is also the approach that the Navy and NIMA have authorized for updating geospatial information in Vector Product Format (VPF) through a concept termed Vector Product Format Digital Update (VDU). The problem with this approach is that to date, NIMA has only been able to update a product by recompiling it and making it available or transmitting the entire product over the net. This solution requires unacceptable communications bandwidth and throughput. Additionally, this solution would lead to doctrine prohibiting intelligent agents from querying local versus library databases to determine which local products to update automatically.

An alternative solution is keeping all geospatial information products at NIMA's informational libraries, distributed regional libraries, and local data stores. This would require users to access and download geospatial information each and every time. Similarly, this solution requires unacceptable communications bandwidth and throughput, and will likely not satisfy operational requirements for geospatial information.

An alternative approach is to use an object-oriented approach for handling data within a relational database. As discussed in chapter VI, an object-relational database management system has many advantages. The system allows the benefits of object-oriented organization of graphical data to be exploited within the well-known relational database environment. However, this approach must still receive and integrate updates, which raises the same issues associated with data transformations and data exchange format standards.

A better approach is to use a pure object-oriented approach with object-oriented databases, such as geospatial information database (GIDB) being experimented with by the Naval Research Laboratory. In this case, geospatial information can be transmitted in its original format, e.g. text as text product standard, imagery as raster product format, or as part of an object bundle. More importantly, entities can be update by transmitting objects that update or replace objects stored within the local object-oriented database. Object-orientation allows for data conversion to the other data format standards for other uses as required, however, why not move all systems towards object orientation? While beyond the scope of this paper, object-orientation is the technological approach that the Defense Advanced Research Projects Agency (DARPA) advocates in their Dynamic Database Program.

Assumption

Legal issues, such as intellectual property rights and copyright issues will be sufficiently resolved with respect to hydrographic organizations exchanging information. These are very important issues that go beyond the scope of this paper. However, the Department of Defense (DoD) and National Imagery and Mapping Agency (NIMA) are actively addressing these issues with cognizant international organizations.

Conclusions

The U.S. Federal Government is one of many users of geospatial information (GI). The Department of Defense (DoD) should continue to work with other users in the community, in particular to articulate DoD geospatial information requirements and to pursue DoD interests in national and international standards and interoperability throughout the different information technology infrastructures.

"Technology continues to develop at a faster pace than acquisition cycles."[214] This is the critical issue against which government agencies and departments must find the proper balance. At odds are expenditure and investment of resources, and production requirements tending towards stove-piped systems versus technological advancements that support the vision, objectives, and goals of future warfare. "Technological development must be realistically tempered by the limitations of fielded and deployed systems and of the consumers themselves."[215] On the other hand, principals such as maintaining an "open architecture" can provide guidance in programming decisions.

"Technologies relevant to the Geospatial Information Infrastructure (GII) are maturing in response to market forces, independent of government action."[216] The Department of Defense (DoD) can benefit from these advances. If DoD insists on an open infrastructure and the associated architectures then systems will be designed to easily upgrade to the latest in technologies and standards. DoD will then be able to afford to upgrade these systems to keep pace with technological advances.

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[214] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 18.

[215] Joint Chiefs of Staff, JTTP for Geospatial Information and Services Support to Joint Operations (Joint Pub 2-03) Final Coordination (Washington D.C.: February 20, 1998), IV-1.

[216] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 17.

"The enabling benefits of web-based technology and a relational database linking the various components that define geospatial requirements will provide customers with an unprecedented way in which to submit and view their geospatial information needs."[217] In the context of geospatial information (GI), web based technologies make sense in a network centric environment. However, the application of this technology must be weighed against the communications bandwidth and throughput requirements. Bandwidth and throughput can be managed by doctrine, techniques, and procedures for how we build an integrated picture of the mission space and what information actually gets sent across the various networks. Moreover, the data exchange format standard can greatly influence these requirements as discussed above.

Advances in technology have resulted in geospatial information (GI) being used in many applications in addition to navigation. Geospatial information is about more than charts. It is the integration and fusion of vector, raster, text, and object data to support all forms of situational displays, software programs, and decision-making processes.

With regards to geospatial information data, beware of commercial data and data products. The issue here is the data – not the system. Commercial data may not be current. When was it last updated? Commercial data may come with disclaimers because of accuracy, currency, resolution, content, and format related issues. Through the certification process NIMA is guaranteeing their data will satisfy legal requirements.

Advances in navigation have resulted in positional accuracy exceeding cartography standards for paper and most electronic navigation charts. The inaccuracies associated with map generalization and displacement are no longer acceptable for new navigation and

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[217] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 35.

weapon systems. Accuracy and content of digital geospatial databases are issues that are currently being addressed and will require continuous maintenance. NIMA's priority is to complete and distribute their vector-based products. In conjunction with the Oceanographer of the Navy, Coast and Geodetic Survey, and other international hydrographic organizations, NIMA will continue to collect data to update and populate their products to meet users mission requirements.

International organizations will continue to lag behind governments, government agencies, non-government organizations, commercial, and the private sector in adapting to geospatial information related technologies, resulting in dated, or a lack of, international policies and standards; due to their organization structure and efficiency. History has already documented this. Federal and Department of Defense policy will need to continue to account for this as well as champion these issues in the international community.

The research for this paper determined that the Navy is the only services that has a stated policy and has directed the use of vector products. As discussed in chapter XI, the Marine Corps is experimenting with object-oriented databases. The Army (with the greatest number of craft operating in the littoral environment) has not weighed in, nor has the Army been invited to participate in discussions between the Navy and NIMA on geospatial information maritime related issues. Similarly, the Navy and NIMA have not successfully engaged the U.S. Coast Guard (USCG) or the National Ocean Service (NOS). The U.S. Coast Guard (USCG) does not have a stated policy, but is keeping their options open by supporting both the international "S-57" standard as well as the NIMA Vector Product Format standard. The National Ocean Service (NOS) commercial orientation has led them to support both raster product format and the international "S-57" standard.

Littoral, Expeditionary, and Network Centric Warfare require seamless geospatial information about the land, air, and sea mediums. The demand for geospatial information goes beyond vector-based maps. Today, forces require geospatial information that exist in Raster Product Format (RPF), Vector Product Format (VPF), and Text Product Format. In the future, forces will likely need to access object-oriented databases. All Department of Defense Services, in fact, all Governmental Departments and Agencies involved in national security, need geospatial information that can be readily integrated and fused with products and information from all the above standard formats.

Recommendations

The Department of Defense should take the lead and work across all federal departments, agencies, and services to reach a shared vision, objects, policy, strategy, and roadmap for geospatial information. This approach should avoid stove-piped systems and embrace technology advances.

NIMA, in conjunction with DARPA and service laboratories, research and develop an open architecture - multilevel security system to facilitate dissemination of disclosable and releasable information to US, allied, and/or coalition operational commanders.

Based on the discussion above for handling and updating geospatial information, recommend object-oriented databases and object-oriented database management system as the database and database management system of choice. Balancing production requirements against technology and future concepts, recommend that NIMA continue to produce and distribute vector product format based products. At the same time NIMA should continue to transition this data to object-oriented data structures for updating existing products and eventual shift to pure object-oriented databases.

ABBREVIATIONS

AOI------------------------------------ Area of Interest
AOR------------------------------------ Area of Responsibility
API------------------------------------ Application Program Interface
BC------------------------------------- Bottom Contour
BNPC---------------------------------- Bathymetric Navigation Planning Chart
CD-ROM------------------------------- Compact Disk – Read Only Memory
CGS----------------------------------- Coast and Geodetic Survey
COMOPTEVFOR--------------------- Commander, Operational Test and Evaluation Force
COTS---------------------------------- Commercial Off-the-Shelf
DARPA-------------------------------- Defense Advanced Research Project Agency
DBDB---------------------------------- Digital Bathymetric Database
DBMS--------------------------------- Database Management System
DGPS---------------------------------- Differential Global Positioning System
DII------------------------------------- Defense Information Infrastructure
DLA------------------------------------ Defense Logistics Agency
DMA----------------------------------- Defense Mapping Agency
DMAP--------------------------------- Digital Mapping Charting and Geodesy Analysis
                                        Program
DNC®--------------------------------- Digital Nautical Chart
DoC------------------------------------ Department of Commerce
DoD------------------------------------ Department of Defense
DoT------------------------------------ Department of Transportation
DTED---------------------------------- Digital Terrain Elevation Data
ECDIS--------------------------------- Electronic Chart Display and Information System
ECDIS-N------------------------------ Electronic Chart Display and Information System-Navy
ECS------------------------------------ Electronic Chart System
ENC----------------------------------- Electronic Navigation Chart
FLIR----------------------------------- Forward Looking Infrared
FUND--------------------------------- Full Utility Navigation Demonstration
GBS------------------------------------ Global Broadcast System
GeoSym™----------------------------- Geospatial Symbology
GI-------------------------------------- Geospatial Information
GIDB----------------------------------- Geospatial Information Database
GII------------------------------------- Geospatial Information and Infrastructure
GI&S----------------------------------- Geospatial Information and Services
GIS------------------------------------ Geographic Information System
GOTS---------------------------------- Government Off-the-Shelf
GPS------------------------------------ Global Positioning System
GSDI----------------------------------- Global Spatial Data Infrastructure
IEC------------------------------------- International Electro-technical Committee
IHO------------------------------------- International Hydrographic Organization
IMO------------------------------------ International Maritime Organization
IT-------------------------------------- Information Technology
JMTK---------------------------------- Joint Mapping Tool Kit

JV 2010----------------------------------- Joint Vision 2010
JWAC------------------------------------- Joint Warfare Analysis Center
JWICS------------------------------------ Joint Worldwide Intelligence Communications System
LLLTV----------------------------------- Low Level Light Television
LORAN----------------------------------- Long Range Navigation
LWD-------------------------------------- Littoral Warfare Data
MC&G------------------------------------- Mapping Charting and Geodesy
MSC-------------------------------------- Maritime Safety Committee
MSDS------------------------------------- Mission Specific Data Sets
N096------------------------------------- Oceanographer of the Navy
NII--------------------------------------- National Information Infrastructure
NIMA-------------------------------------National Imagery and Mapping Agency
NIMAMUSE----------------------------------NIMA MC&G Utility Software Environment
NOAA------------------------------------- National Oceanic and Atmospheric Administration
NOS--------------------------------------National Ocean Service
NSDI--------------------------------------National Spatial Data Infrastructure
ODBMS----------------------------------- Object-oriented Database Management System
ODNC------------------------------------ Object Digital Nautical Chart
OO-- Object-oriented
OOPS------------------------------------- Object-oriented Programming
OVPF------------------------------------- Object Vector Product Format
RDBMS----------------------------------- Relational Database Management System
RPF--------------------------------------- Raster Product Format
SAR---------------------------------------Synthetic Aperture Radar
SDNC------------------------------------- System Digital Nautical Chart
SENC------------------------------------- System Electronic Nautical Chart
SIPRNET--------------------------------- SECRET Internet Protocol Router Network
SOLAS------------------------------------ Safety of Life at Sea
TOD--------------------------------------- Tactical Ocean Data
TPS--------------------------------------- Text Product Standard
USCG-------------------------------------U.S. Coast Guard
USIGS------------------------------------United States Imagery and Geospatial Information
Services
USN--------------------------------------U.S. Navy
VDU-------------------------------------- Vector Product Format Digital Update
VPF--------------------------------------- Vector Product Format
WGS-84----------------------------------- World Geodetic System 1984
WVS-------------------------------------- World Vector Shoreline
WVS+------------------------------------- World Vector Shoreline Plus
WVS-VPF------------------------------- World Vector Shoreline – Vector Product Format

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<http://oceanographer.navy.mil/gi&s_hbk.html> (11 January 1999)

APPENDIX A

Gateway Services	Networks	Environment	Workstation/ Operating System
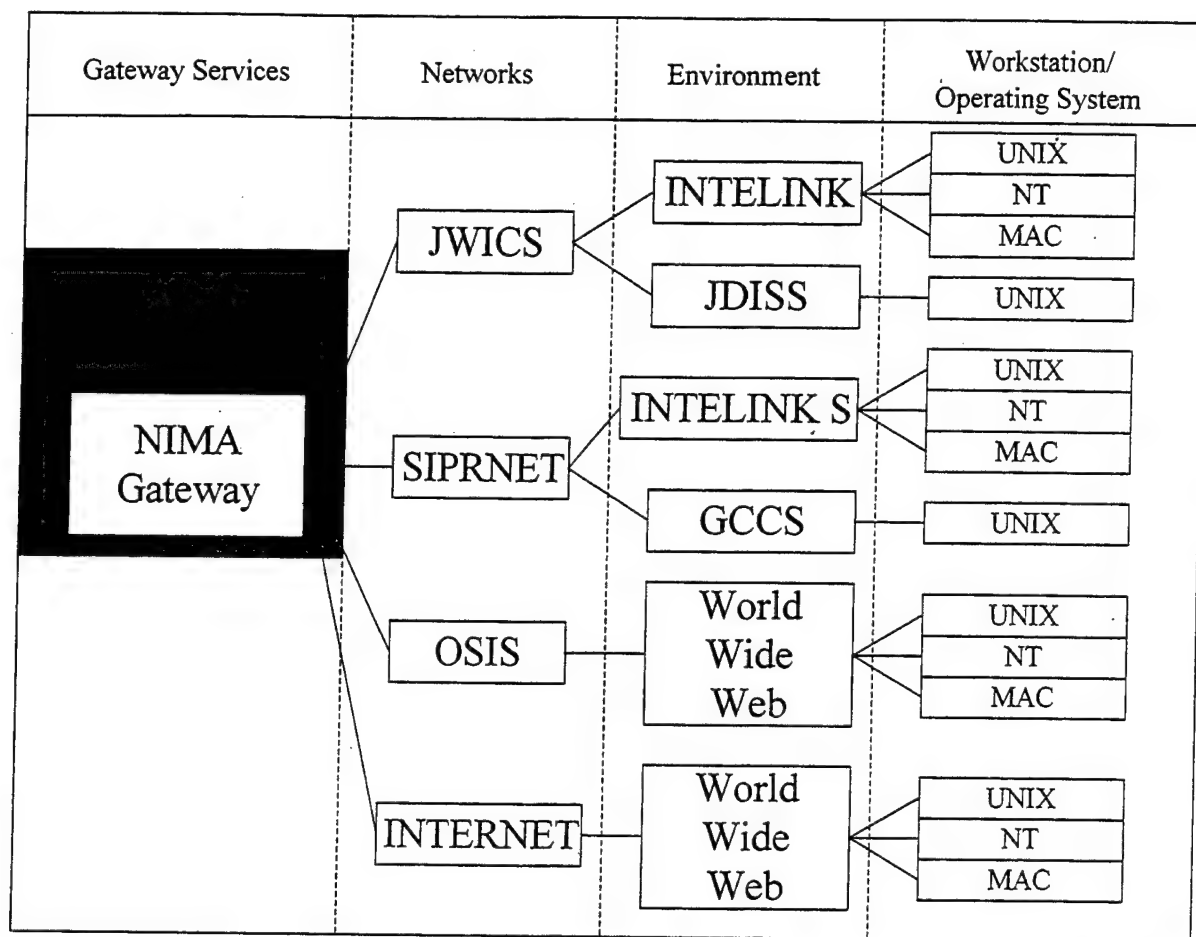
Figure 1[1]

Geospatial Information and Services Gateways

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[1] Modified from illustration in John W. Strebeck, <u>Enhancing Battlespace Awareness By Centralizing National Imagery and Mapping Databases: A Force Multiplier</u>, (Naval War College, Newport, Rhode Island: 13 June 1997) 15.

Appendix A

GEOSPATIAL INFORMATION AND SERVICES COMMUNICATIONS SYSTEM ARCHITECTURE

Combatant Commander

- GBS
- DODIIS
- JWICS
- INTELINK
- SIPRNET
- GCCS
- Internet
- Other

GI&S Warehouse

Subordinate JFC

Analysis
C2
Modeling & Simulation

Targeting
Decision making
Navigation
Visualization

DODIIS	DOD Intelligence Information System	JFC	Joint Force Commander
GBS	Global Broadcast Service	JWICS	Joint Worldwide Intelligence Communications System
GCCS	Global Command and Control System	SIPRNET	SECRET Internet Protocol Router Network

Figure 2[2]

Geospatial Information and Services Communications System Architecture

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[2] Joint Chiefs of Staff, JTTP for Geospatial Information and Services Support to Joint Operations (Joint Pub 2-03) Final Coordination (Washington D.C.: February 20, 1998), IV-4.
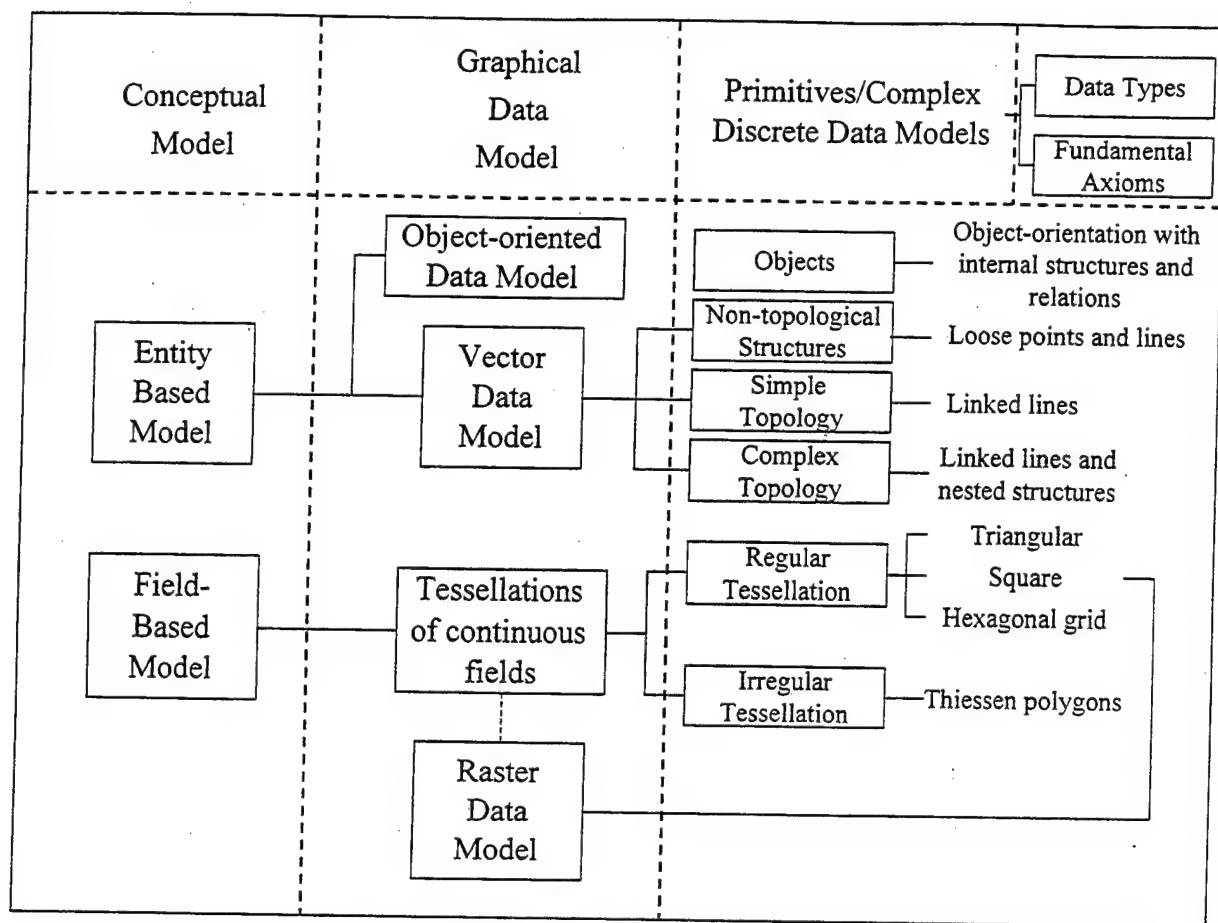
Figure 3[3]

Geographical Data Models

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[3] Tessellation is the process of dividing an area into smaller, contiguous tiles with no gaps in between them. Thiessen polygons are defined as a tesselation of the plane such that any given location is assigned to a tile according to the minimum distance between it and a single, previously sampled point.

Appendix A
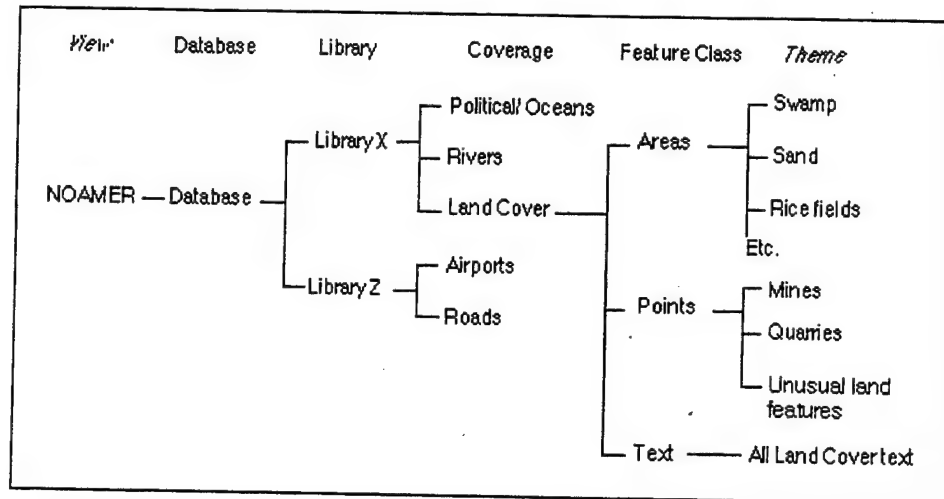
Figure 4

Vector Product Format Data Structure
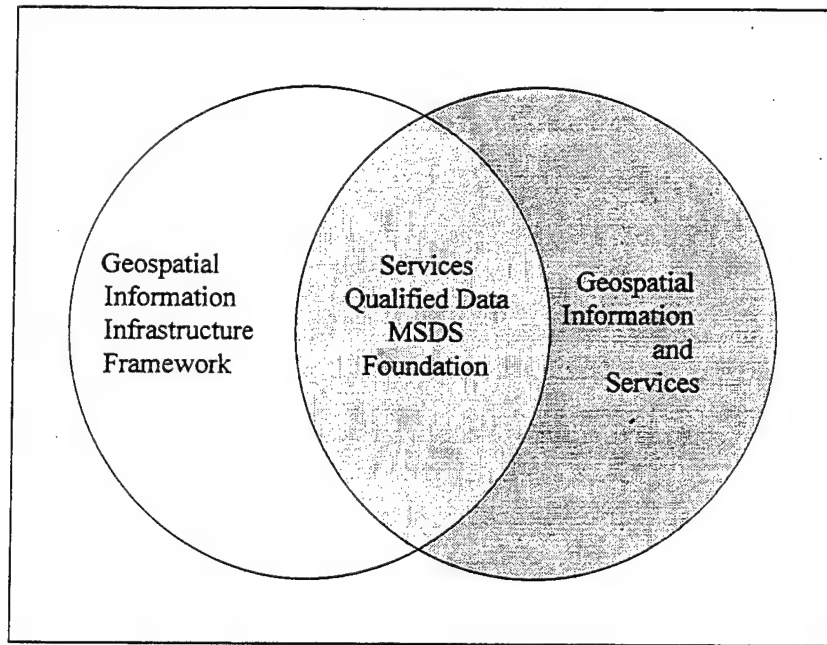
Figure 5

GII Framework and GI&S Inter-relationship
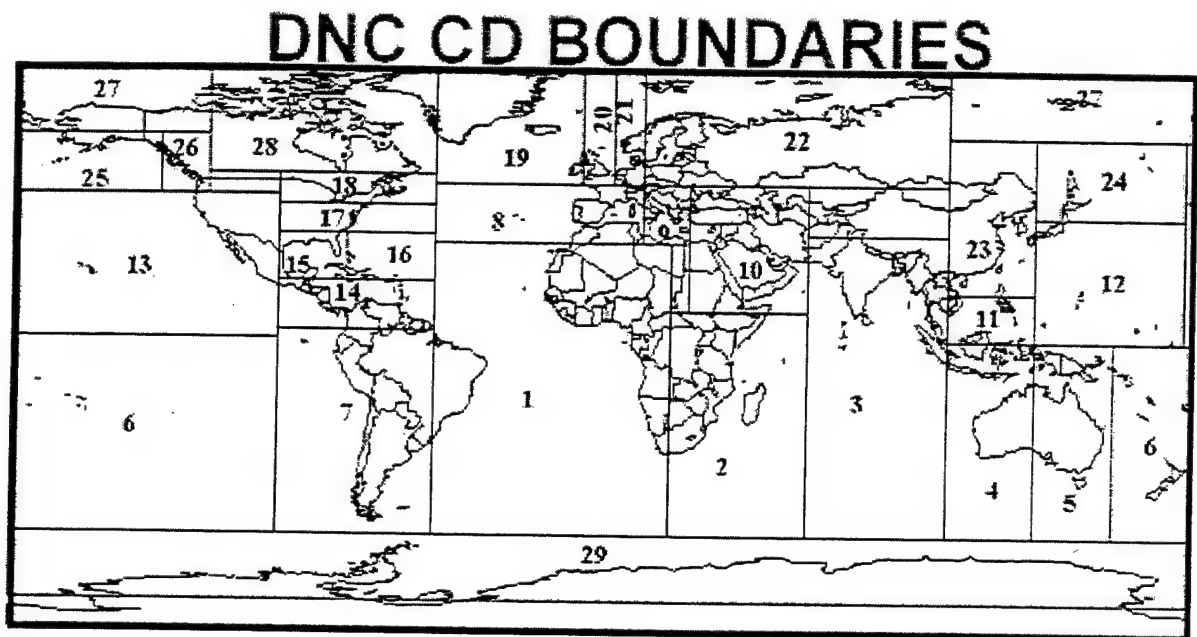
DNC CD BOUNDARIES

Figure 6

DNC® Compact Disk Boundaries [4]

[4] National Imagery and Mapping Agency, "Digital Nautical Chart (DNC) CD Boundaries/Production," Digital Nautical Chart, 28 January 1999, <http://www.nima.mil/dnctest/NIMA_CD_BOUNDARIES> (3 February 1999).
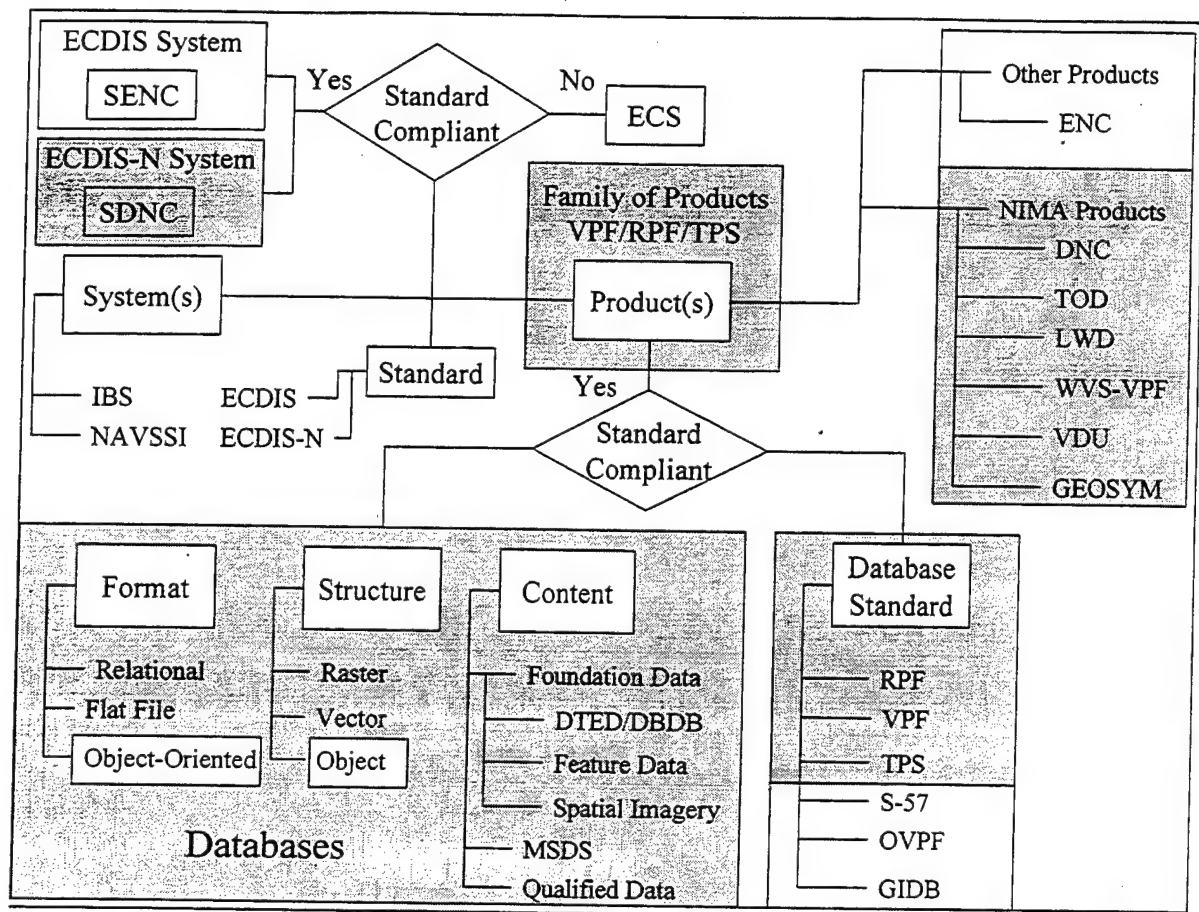
Figure 7

Data, Databases, Products, Systems, and Standards

APPENDIX B

Appendix B

The creation of digital spatial data sets involves seven levels of model development

and abstraction as listed below:

Table I[1]

Spatial Data Models and Data Structures

A view of reality (conceptual model);
Human conceptualization leading to an analog abstraction (analog model);
A formalization of the analog abstraction without any conventions or restrictions on implementations (spatial data model);
A representation of the data model that reflects how the data are recorded in the computer (database model);
A file structure, which is the particular representation of the data structure in the computer memory (physical computational model);
Accepted axioms and rules for handling the data (data manipulation model);
Accepted rules and procedures for displaying and presenting spatial data to people (graphical model).

[1] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 18.

Table II[2]

Fundamental Geospatial Information Axioms

In Geographical Information Systems "the primitive entities are points, lines, polygons, and pixels (grid elements). Complex entities having a defined internal structure can be built from sets of points, lines, and polygons.
All fundamental entities are defined in terms of their geographical location (spatial coordinates or geometry), their attributes (properties) and relationships (topology). These relationships may be purely geometrical (with respect to relations or neighbors), or hierarchical (with respect to attributes) or both.
Individuals (entities) are distinguishable from one another by their attributes, by their location, or by their internal or external relationships.
New entities (or sets of entities) can be created by geometrical union or intersection of existing entities...
New complex entities or objects can be created from the basic point, line, area or pixel entities.
New attributes can be derived from existing attributes by means of logical and/or mathematical procedures or models" or "from existing topological relations and from geometric properties...or by interpolation.
Entities having certain defined sets of attributes may be kept in separate sub-data sets called data planes or overlays.
Data at the same XYZt coordinate can be linked to all data planes (the principle of the common basis of location).
Data linked to any single XYZt coordinate may refer only to an individual at that coordinate, or to the whole of an individual in or on which that point is located.
New attribute values at any XYZt location can be derived from a function of the surroundings (e.g. computation of slope, aspect, connectivity).

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[2] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 18.

Table III

Considerations in Picking the Right Geographic Data Model[3]

If the location and form of the entity is unchanging and needs to be known accurately, but the attributes can change to reflect differences in its state caused by inputs of new data or output from a numerical model, then the vector representation of the entity model is appropriate. This is the most common situation in conventional Geographic Information Systems.
If the attributes are fixed, but the entity may change form or shape but not position, as in the drying up of a lake, then a vector model requires a redefinition of the boundary every time the area of the lake changes. A raster model of a continuous field, however, would treat the variation of the water surface as a response surface to a driving process so that the extents of the lake could be followed continuously.
If no clear entities can be discerned, then it is often preferable to treat the phenomenon as a discretized, continuous field.

Cadastre, the division and ownership of land, works well in a vector data model, "using nominal, integer, and real data types to record the attributes and real data types for the coordinates." Utility networks location, attributes, and contextual relationships "can be incorporated in a data model of topologically connected lines (entities) that are described by attributes. Data types may include all forms." Land cover databases can be modeled by vector or raster data models depending on how the data has been collected and partly on the way it will be used. Hydrology is best modeled based "on ideas of object-orientation in which primitives entities are linked together in functional groups... The internal structure of the data model permits action on one component of the group to be passed automatically to other parts; consequently the data model contains not only geographical location, geometry, topology, and attributes but also information on how all these react to change."[4]

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[3] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 29.

[4] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 30-32.

Table IV[5]

Raster and Vector Data Structures – A Qualitative Comparison

RASTER DATA	VECTOR DATA
Advantages	Advantages
Simple data structures.	Good representation of entity data model.
Location-specific manipulation of attribute data is easy.	Compact data structure.
Many kinds of spatial data analysis and filtering may be used.	Topology can be described explicitly – therefore good for network analysis.
Mathematical modeling is easy because all spatial entities have a simple regular shape.	Coordinate transformation and rubber sheeting is easy.
The technology is cheap.	Accurate graphic representation at all scales.
Many forms of data are available.	Retrieval, updating and generalization of graphics and attributes are possible.
Disadvantages	Disadvantages
Large data volumes.	Complex data structures.
Using large grid cells to reduce data volumes reduces spatial resolution, result in loss of information and an inability to recognize phenomenologically defined structures.	Combining several polygon networks by intersection and overlay is difficult and requires considerable computing power.
Crude raster maps are inelegant though graphic elegance is becoming much less of a problem today.	Display and plotting may be time consuming and expensive…
Coordination transformations are difficult and time consuming unless special algorithms and hardware are used and even then may result in loss of information or distortion of grid cell shape.	Spatial analysis within basic units such as polygons is impossible without extra data because they are considered to be internally homogeneous.
	Simulation modeling of processes of spatial interaction over paths not defined by explicit topology is more difficult than with raster structures because each spatial entity has a different shape and form.

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[5] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 70.

Table V[6]

Database Management System Functionality

Allow storage and retrieval of data and data selection based on one or more attributes or relations.
Standardized access to data, and separate data storage and retrieval from the use of data and in application programs to maintain independence in those programs.
Provide an interface between database and application program based on a logical description of the data without requiring details of the physical storage.
Make access functions in applications independent of the physical storage structure so that programs are not affected by changes in storage media.
Allow several users to access the data simultaneously.
Protect the database from indiscriminate and illegal changes.
Provide sound rules for data consistency which will be enforced automatically.

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[6] Peter A. Burrough and Rachael A. McDonnell, <u>Principles of Geographical Information Systems</u> (Oxford: Oxford University Press, 1998) 50.

Appendix B

Table VI[7]

Hybrid Relational Database Management System Advantages

Attribute data need not be stored with the spatial database but may be kept anywhere on the system, or even on line via network.
Attribute data can be expanded, accessed deleted, updated without having to modify the spatial database.
Commercial Relational Database Management System (RDBMS) ensure that new developments are incorporated as standard.
Data structures may be defined in standard ways using data dictionaries; data can be retrieved using general methods such as standard query language (SQL) that are independent of the Relational Database Management System (RDBMS).
Keeping the attribute data in a Relational Database Management System (RDBMS) does not interfere with the basic principles of layers in a Geographic information System (GIS).
Attributes in a Relational Database Management System (RDBMS) can be linked to spatial units that may be represented in a wide variety of ways.

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[7] Peter A. Burrough and Rachael A. McDonnell, Principles of Geographical Information Systems (Oxford: Oxford University Press, 1998) 71.

Appendix B

Table VII

Relational-hybrid GIS versus Object-Orientation

RELATIONAL-HYBRID GIS	OBJECT-ORIENTATION
Advantages	Advantages
Modifiability of spatial data after inputting to the system.	The semantic gap between the real-world objects and concepts and their representation in the database is less than with relational databases.
Data retrieval and modeling functionality is provided by the DBMS.	The storage of both the state and the methods ensures database maintenance is minimized.
Easy data integration from other systems particularly for the attribute data.	Raster and vector data structures may be integrated in the same database.
All aspects of the data are stored in a specialized file structures.	The data exchange of objects is supported.
Ease of use.	Fast querying of the database especially when complex objects and relationships have to be dealt with as fewer join operations are needed.
Sound theoretical foundation for relational database.	Requires less disk space than relational entities...
	Enables user-defined functions to be used.
Disadvantages	Disadvantages
Poor handling of temporal data.	There is no universally accepted object-oriented model so different database products have different standards and tend to be tied to one particular O-O language.
Coordinate data tend not to be subject to the rigorous database management as might be applied to attribute data, so issues of security and integrity exist.	Identifying objects is often difficult, particularly in continuous spatial surfaces.
Relies on the spatial position or attribute value for querying or modeling.	Requires the definition of functions and topology as well as objects.
Slow handling of querying especially when dealing with complex objects.	Limited application of indexing because of the incompatibility of it with the notion of encapsulation and object-identity.
Querying and modeling limited to functionality provided by the GIS (or data must be exported)	No established standards such as SQL and provisions for a general query language...is made difficult by the complexity of the object types in the system
	There is less theoretical and practical experience with O-O approach than the hybrid method.

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Table VIII[8]

Geospatial Information and Services and Resident Exploitation Capabilities

Generate views of the mission space (e.g., topographic line map representations, littoral warfare data, political boundaries, aeronautical flight information).
Create composite image maps.
Create 3-D perspective views and fly-throughs.
Accurately register and compile other geospatial coverages and views, as well as information from other domains.
Add additional details to coverages and attribute information to features.
Conduct spatial analysis such as mobility or line of sight.
Orient and link the results of analysis to the earth's surface.

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[8] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 29-30.

Table IX[9]

Geospatial Information and Services and
Geospatial Information Infrastructure Framework Benefits

A consistent and documented set of Foundation Data with near global coverage.
The ability to intensify the Foundation to meet specific mission information needs.
Consistent data quality information (positional accuracy, currency, completeness, correctness of attribution) to support more informed exploitation by users.
Improved access to digital information using web-based technologies.
Interoperability of geospatial information across diverse systems and among co-producers.
More robust analytical capabilities.
Ability to add local user data or exploit data from other providers to create tailored views.

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[9] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 31.

Table X[10]

An Integrated View Does Not Imply Perfect Knowledge.

An Integrated View Means
A shared set of Framework Information and Services.
Effective fusion of information from many domains.
Information with known characteristics (geospatial information with content, accuracy, and resolution that is consistent with the mission).
Doctrine, training, and tools that produce repeatable and consistent results.
Standard conventions for passing coordinates in common horizontal (World Geodetic System 1984, WGS-84) and vertical reference systems.
Standard naming conventions for feature identification and attribution.
Standard symbology for geospatial information.
Standard data exchange format(s) for sharing information.
An Integrated View Does Not Mean
Error-free geospatial information.
Completely logical, deconflicted information from all sources.
Perfect knowledge of the mission space.
Identical views of the geospatial information for users within the mission space.

[10] Integrated Product Team, Geospatial Information Infrastructure Master Plan: Vol. I, Overview, (Fairfax, VA: National Imagery and Mapping Agency, 17 October, 1997), 10-11.

Table XI[11]

NIMA's Existing Products

ARC Digitized Raster Graphics (ADRG)
ARC Digital Raster Imagery (ADRI)
Automated Air Facilities Information File (AAFIF)
Compressed Aeronautical Chart (CAC)
Digital Aeronautical Flight Information File (DAFIF)
Digital Bathymetric Data Base (DBDB)
Digital Chart of the World (DCW)
Digital Feature Analysis Data Level 1 (DFAD1)
Digital Feature Analysis Data Level 1-C (DFAD1-C)
Digital Feature Analysis Data Level 2 (DFAD2)
Digital Feature Analysis Data Level 3-C (DFAD3-C)
Digital Terrain Elevation Data Level 1 (DTED1)
Digital Terrain Elevation Data Level 2 (DTED2)
Digital Nautical Chart (DNC)
Interim Terrain Data (ITD)
Mapping Datum Transformation Software Program (MADTRAN)
Mapping, Charting & Geodesy Video Laser Disc (VLD)
Navigation Information Network (NAVINFONET)
Probalistic Vertical Obstruction Data (PVOD)
World Mean Elevation Data (WMED)
World Vector Shoreline (WVS)

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[11] National Imagery and Mapping Agency, <u>Digital Nautical Chart</u>, January 06, 1999, <http://164.214.2.54/guides/dtf/dnc.html> (February 1, 1999).

Table XII[12]

NIMA's Prototype Products

Controlled Image Base (CIB)
Controlled Multispectral Image Base (CMIB)
Compressed ARC Digitized Raster Graphics (CADRG)
Compressed Raster Graphics (CRG)
Electronic Chart Updating Manual (ECHUM)
Digital Gazetteer (DG)
Digital Sailing Directions (DSD)
Digital Topographic Data (DTOP)
Interim Terrain Data on CD-ROM (ITD-CDR)
Tactical Terrain Data (TTD)
Vector Smart Map Level 0 (Vmap0)
Vector Smart Map Level 1 (Vmap1)
Vector Smart Map Level 2 (Vmap2)
Vector Smart Map Urban (UVMap)
World Vector Shoreline - Vector Product Format (WVS-VPF)

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[12] National Imagery and Mapping Agency, Digital Nautical Chart, January 06, 1999,
<http://164.214.2.54/guides/dtf/dnc.html> (February 1, 1999).

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Table XIII[13]

Standard Products That Support Navigation Onboard U.S. Navy Vessels

PAPER PRODUCT	DIGITAL PRODUCT EQUIVALENT
General, Coastal, Approach, & Harbor	Digital Nautical Chart (DNC®)
Operating Areas, Range Markings	Tactical Ocean Data (TOD) 0
Bottom Contour (BC)	Tactical Ocean Data (TOD) 1
Bathymetric Navigation Planning Chart (BNPC)	Tactical Ocean Data (TOD) 2
Combat Chart	Littoral Warfare Data (LWD)
Notice to Mariners	Vector Database Update (VDU)

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[13] Modified from National Imagery and Mapping Agency, <u>Digital Nautical Chart</u>, January 06, 1999, <http://164.214.2.54/guides/dtf/index.html> (February 1, 1999).

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Table XIV[14]

DNC® CD-ROM Availability and Status

DNC® CD-ROM - Geo Region	Edition	Projected	Release Date	Comp.	NSN No.
1 South Atlantic Ocean	2nd		Jan 99	3%	7644014408230
2 East Africa		(3/99)			TBD
3 Indian Ocean	2nd		Feb 98	21%	7644014398358
4 Western Australia	1st		June 98	12%	7644014482124
5 Eastern Australia	1st		Sept 98	37%	7644014482129
6 South Pacific Ocean	1st		Oct 98	27%	7644014482131
7 South America	1st		Aug 98	31%	7644014578371
8 Southern Europe-Western Med.	2nd		May 98	30%	7644014354834
9 Central Mediterranean	3rd		Nov 98	59%	7644014332876
10 Middle East-Persian Gulf	3rd		Mar 98	81%	7644014381568
11 South China Sea	2nd		Feb 99	14%	7644014499671
12 Japan/North Pacific	2nd		Jan 98	20%	7644014474190
13 North America-West	2nd		Dec 97	71%	7644014414461
14 Central America-Carribean Sea	4th		Apr 98	42%	7644014337948
15 Gulf of Mexico/Florida Straits	8th		Nov 98	50%	7644014337963
16 Bahamas/Bermuda	5th		Dec 98	30%	7644014337966
17 Eastern United States	6th		July 98	100%	7644014337969
18 Northeast US/Canada	2nd		Aug 98	16%	7644014562137
19 Greenland/Iceland/UK	1st		Aug 98	24%	7644014562140
20 United Kingdom		(1/99)			TBD
21 Norway		(3/99)			TBD
22 Barents Sea	1st		Dec 98		7644014609963
23 Northern Asia	2nd		Sept 98	53%	7644014360296
24 Sea of Okhotsk	1st		Feb 98	40%	7644014482139
25 Gulf of Alaska	1st		Mar 98	24%	7644014482141
26 British Columbia	1st		Jan 98	23%	7644014421035
27 Arctic Ocean		(6/99)			TBD
28 Canada		(5/99)			TBD
29 Antarctica		(9/99)			TBD

[14] National Imagery and Mapping Agency, "DNC® CD-ROM Availability and Status," Digital Nautical Chart, 28 January 1999, <http://www.nima.mil/dnctest/NIMA_CD-Rom_Availability.html> (3 February 1999).

Table XV[15]

DNC® Feature Layers/Coverages

THEMATIC LAYER	CONTENT
Culture	Land features of human origin - Roads, Buildings, Industrial areas.
Earth Cover	Topographic and hydrographic features – Shoreline, Islands, and International boundaries.
Environment	Ocean currents, Tides, and Magnetic anomalies.
Hydrography	Depth curves, Soundings, Bottom characteristics and a new feature unique to electronic navigation Depth areas.
Inland Waterways	Inland hydrographic features – rivers, lakes, and canals.
Land Cover	Shore features significant to navigation Trees, Glaciers, Swamps, Marshes.
Limits	Significant to navigation Pilot boarding locations, Restricted maritime areas, and Traffic separation schemes.
Navigation Aids	Marine navigation aids, Buoys, Lights, and Beacons to name a few
Obstructions	Rocks, Wrecks, Bridges and just about every feature that is considered a hazard to navigation safety
Ports	Unique features common in most ports Breakwaters, Piers, Wharves, Jetties, and Berths
Relief	Topographic spot elevations and contours
Data Quality	Everything you wanted to know about the paper source chart or survey used in the compilation of the DNC. Provides historical data, edition, Datum information, and related notes.
Library Reference	Small scale depiction of the Chart coverage for use in selecting a geographic reference position for viewing.

[15] Zdenka S. Willis, CDR, USN, and others, Geospatial Information & Services Maritime Navigation Handbook, Version 2.0, 20 April 1998. <http://oceanographer.navy.mil/gi&s_hbk.html> (11 January 1999).

Table XVI[16]

Characteristics of ECDIS Compliant Systems

Stores nautical charts and displays them on a computer screen.
Eliminates the need for paper charts because the stored charts are their legal and visual equivalents.
Integrates into the chart display the position, speed and heading of the ship, which is updated continuously to show the actual current position and which keeps track of past motion.
Allows radar to be overlayed so that position, direction, depths and obstructions or other vessels can be observed at once.
Allows the chart to be updates.
Allows information to be removed or replaced at will.

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[16] Irene M. Gonin and others, Electronic Chart Display and Information System (ECDIS) Test and Evaluation, Summary Report, U.S. Coast Guard Research and Development Center, Report No. CG-D-20-97. (Groton, Connecticut: December 1996).

Table XVII[17]

ECDIS-N Compliant System Functionality

Displaying all chart information necessary for safe and efficient navigation.
Facilitating simple and reliable updating of the electronic navigational chart.
Reduce the navigational workload as compared to use of a paper chart.
Have at least the same reliability and availability of presentation as the paper chart.
Provide appropriate alarms or indications with respect to the information displayed or malfunction of the equipment.
Radar information or other navigation information (e.g. line of position fix, dead reckoning plot) may be added to the ECDIS-N display.
ECDIS-N also addresses performance standards for route planning, route monitoring, and voyage recording.

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[17] Chief of Naval Operations, "U.S. Navy Electronic Chart Display and Information System Policy," Serial N00/8U5000076 of 17 March 1998, (Washington, D.C.).

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Table XVIII[18]

Mandated Standards and Functional Requirements
for ECDIS-N and Associated Electronic Charts

Navy standard automated and continuous positioning systems and approved navigation and piloting procedures shall be used for position reference. In addition to accepting continuous position systems for navigation and piloting, EDCIS-N shall accept radar and visual navigation fix information.
Standard products and services are defined as those which are produced by NIMA. NIMA produces all electronic charts on WGS-84, maintains these products, and provides them directly to the fleet.
World Geodetic System-84 (WGS-84) is the standard horizontal datum.
Vector Product Format (VPF) is the standard digital data format that will support ECDIS-N onboard all US Navy vessels.

[18] Chief of Naval Operations, "U.S. Navy Electronic Chart Display and Information System Policy," Serial N00/8U5000076 of 17 March 1998,(Washington, D.C.).

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